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EFFECTS OF HIGH LEVELS OF POTASSIUM AND MAGNESIUM SULPHATES ON TOMATOES

By D. W. T. CLAY* and J. P. HUDSON
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In previous experiments tomato plants grown in glasshouses were subjected to different water-regimes, in which the soil was allowed to dry out to various definable conditions before water was applied. In a coarse sandy loam soil, with low concentrations of soluble salts, there was little response to irrigation during the early stages of development, i.e. at a time when roots were still growing strongly into new areas of soil containing freely available water (Salter, 1957). Thereafter, when the rooting zone had been occupied, the plants became sensitive to surprisingly small water deficits, and the heaviest yields of tomatoes were always obtained where water was applied frequently and soil moisture tension was not allowed to rise by more than a few centimetres of mercury (Salter, 1954 and 1957).

The generally accepted concept is that water uptake is related both to soil moisture tension and to the osmotic pressure of the soil solution, the sum of the two representing the "total soil moisture stress" of Wadleigh and Ayers (1945.) In Salter's experiments, the soil was thoroughly leached by flooding each winter, as in normal commercial practice, and the content of soluble salts was therefore maintained at a low level, although there may have been a slight accumulation of unused fertilizers towards the end of each season. It is, therefore, assumed that osmotic pressure of the soil solution did not make an important contribution to total soil moisture stress in the earlier work, and the treatment effects are considered to have been mainly due to differences in moisture tension.

As a further step in the study of the water relations of tomato plants, the effects of soil salinity† and the osmotic pressure associated with high salinity have been studied, during two growing seasons, by bringing the soil to different levels of salinity before planting and keeping it moist at all times to prevent moisture tension from contributing substantially to total moisture stress. This was done by adding various amounts of salts to the plots before the season began and rewetting to field capacity whenever 5% of available water had been removed from the soil at any level in the rooting zone.

Methods.

The experiments were carried out in the twenty-four brick-lined plots and four lysimeters, each approximately 1/1000th acre, described by Salter. Ten plants of each of two varieties were planted in each plot, three of each variety in the middle of the plots being regarded as the main experimental plants.

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† Many terms are used in referring to the salts in a soil. All soils contain soluble salts, and therefore have a degree of salinity, but the term " saline " is generally used to refer to soils which contain greater amounts of salts than are found in normal soils of humid regions, where rainfall is sufficient to cause leaching and thus prevent accumulation of soluble salts.

Preparation of the soil.

The beds were double dug each winter and farmyard manure was incorporated in the soil at the rate of 50 tons per acre. In preparation for the 1956 experiment, but not for that of 1957, the beds were then thoroughly leached by applying 50 gallons of water four times to each bed over a period of six days (a total of about 200,000 gallons per acre), whereby the salinity status was reduced to a low level throughout the whole depth of soil.

Salinity treatments.

Soil can be salinized for experimental purposes in a number of ways (Richards, 1954), several of which could have been used in the present work, where a comparatively large volume of soil had to be treated, but it was decided to dissolve the salts in a large volume of water, considerably more than was required to rewet the whole profile to field capacity, and apply the solution to the surface. Although distribution of salts is thus ensured throughout the rooting zone, weaknesses of the method are that the salts are not evenly distributed down the profile and some of the solution is lost to drainage. The precise amount of salts retained is thus uncertain. However, a series of three preliminary experiments, with columns of soil packed in glazed drainpipes 36 in. long and 6 in. in diameter, suggested that this method would give more satisfactory results than any other system of salinizing large blocks of undisturbed soil. Assessments of salinity at various depths showed that the applications of salt solutions did in fact produce distinctly different conditions of salinity in the different treatments, although there was an initial high concentration of salts in the surface layers in all and a regular decline of salinity with depth. These differences were greatly reduced by downward leaching of salts as the season advanced.

It was difficult to decide on the choice of salts for salinizing. The ideal would have been to use a salt which is normally present in quantity in glasshouse soils but which is of little nutritive value, so as to avoid nutritional effects. The salt which most nearly meets these conditions is calcium sulphate (gypsum), but its low solubility makes it unsuitable for producing high salinities. Sodium salts were ruled out on the grounds that the sodium ion might adversely affect soil structure, and that sodium is not normally present in quantity in British glasshouse soils. It was finally decided to use a mixture of potassium sulphate and hydrated magnesium sulphate (Epsom salts) in the proportion of 3:1 by weight, a choice based on the fact that potassium salts have often been found in excessive amounts in old glasshouse soils (Pizer, 1945 ; Skillman, 1954 ; Lamb, 1954), while magnesium sulphate is sometimes applied to glasshouse soils at rates of a ton per acre or more (Walsh and Clarke, 1945 ; Owen, 1949). The use of magnesium sulphate was further justified since it was likely to prevent magnesium deficiency from appearing in plants grown in soils treated with large amounts of potassium.

Measurements of salinity.

The salt content of a soil, as a measure of the total amount of salts either dissolved in the soil solution or present in such a state that the addition of more water will bring them into solution, is often expressed directly as a percentage of the total dry weight, or as parts per million of soil, but it is becoming more common to use the indirect method of measuring and quoting the effect of salts on the conductivity of

the soil solution or of a suspension of soil in water. This measurement is useful because it is related to the effects of soluble salts on the osmotic pressure of the soil solution, which is the attribute affecting uptake of water by plant roots. The work required a method of assessing salinity that was rapid, used relatively small samples of soil, and produced results which were comparable with those of other workers in this field and particularly with the assessments made by the advisory services in Britain*. The method selected, as generally used in Britain, consists of measuring the electrical conductivity of a 1:2½ (wt.:wt.) soil:water suspension, as follows :

> The soil sample is air dried, ground with pestle and mortar and passed through a 1 mm. round-hole sieve. Ten grammes are then placed in a suitable container (e.g. specimen tube of 2·5 cm. diameter) and 25 ml. of distilled water added, shaken, left for 16 hours and re-shaken. After standing for one hour in a water bath at known temperature the electrical conductivity of the suspension is assessed with a conductivity bridge. The figures for electrical conductivity may be converted to the pC scale, introduced by Whittles and Schofield-Palmer (1951) and now widely used by the British advisory services, by taking the common co-logarithm of the specific conductivity measured in mhos/cm. at 20°C. The pC scale ranges from a value of about 4·0 in soil with negligible salinity down to 2·0 or less in very highly saline soils.

There are various objections to this method, notably that the excessive amount of water may take a greater total amount of salt into solution than was present in the soil solution itself, especially where sparingly soluble salts such as calcium sulphate are present, and that the process of preparing the sample for estimation alters the nature of the soil. However, the average initial pC value of the soil was 3·8, which is low compared with that of most glasshouse soils, and the irrigation water contained virtually no dissolved salts, so that errors in determining salinity due to the anomalous behaviour of sparingly soluble salts were probably small in the first part of the present work.

Determinations were made on soil removed immediately before planting from two sites in each plot, at depths of 0-2, 6-8 and 20-22 in., and samples were removed for estimation from two sites per plot, at 4-6 and 20-22 in., on a number of occasions during the growing season.

Irrigation control.

One " key " plot was selected at random for each treatment and six commercial soil moisture tensiometers were installed in each key plot, midway between plants, with the centres of their porous pots 3, 6, 12, 18, 24 and 30 in. below soil level. The stem of a seventh tensiometer was bent at right angles and the pot placed with its longitudinal axis 1½ in. below soil level, to enable fluctuations in soil moisture tension in the surface layers to be followed.

All six beds in a treatment were watered whenever any tensiometer (other than the shallow one) showed a tension of 7 cm. mercury, i.e. when available water in the

* The present position regarding assessment of soil salinity is highly unsatisfactory, since research and advisory services in Britain, the United States, the Netherlands, and elsewhere each use different methods of assessment and state their results in different units. See Richards (1954) for details of the U.S. methods and Winsor and Davies (1958) for valuable comments on the British system.

soil adjacent to the tensiometer pot had fallen from about 27% (field capacity) to about 23%. The amount of water required to re-wet the whole block of soil to field capacity was calculated as by Salter (1954), except that the use of more tensiometers, at various depths, eliminated the need for soil sampling to assess the depth of rooting, since roots could be assumed to have reached the level of the pot of any tensiometer in which readings began to increase. At each watering, the water deficits for each zone were calculated separately from tensiometer readings and known soil characteristics (Majmudar and Hudson, 1957), all deficits for the key plot were summated and the volume of water thus calculated was applied by hosepipe through a water meter to each of the plots in the treatment. Tensiometer readings the day after watering showed that each irrigation re-wetted the whole rooting zone to field capacity.*

Nutrition.

No base dressing was applied before planting, to avoid localized areas of high salinity, but feeding was commenced immediately after planting, using two pints (1·1 litres) of 1:400 liquid fertilizer per plant per week until plants were carrying heavy crops in late June, after which twice that amount was used. The feed consisted of a mixture of ammonium nitrate, potassium nitrate and mono-ammonium phosphate to give a ratio of 1:1:2 $N:P_2O_5:K_2O$. Though adequate for nutrition, these applications had a negligible effect on salinity.

Cultural details and recording.

Training and the removal of side shoots and leaves were carried out as necessary but the main stems were not stopped. As far as possible, heating and ventilation were controlled to keep temperatures below 80°F. by day and between about 55 and 60°F. at night. Fruit was picked thrice weekly and each fruit weighed and checked for blotchy ripening and blossom-end rot.

Estimates were made of the dry weight of aerial vegetative parts (Salter, 1954 and 1956) but, since habit of growth was considerably modified by salt treatments and there was no opportunity of finding regression equations for plants grown under different conditions of salinity, the results are only regarded as approximate.

1956 EXPERIMENT.

Varieties : Ailsa Craig and Potentate.

Seed sown 10th January 1956 ; seedlings pricked off 26th January, planted out 17th March; ball watered 21st March to 10th April (5 times), main watering begun 10th-13th April; first fruits picked 10th May (with blossom-end rot), 30th May (sound fruit); final recording 10th September.

The following amounts of potassium and magnesium salts (3:1 mixture) were dissolved in water in a raised tank and the solutions run on to each plot in two applications of 60 gallons per plot :

S_0, no added salts

* Since writing this account we have seen the paper of Smith, D. E., and Warren, G. F. describing their " Studies of soluble salts in greenhouse soils " (Proc. Amer. Soc. hort. Sci., 1957, **70,** 501-11), which were based on a rather similar experimental approach, though with less control of the moisture status of the soil, with the result that a high total soil moisture stress may have occurred from time to time from drying out between irrigations. The results were nevertheless similar to those reported herein.

S_1, 20 lb. of salt mixture per plot=about 9 tons per acre
S_2, 40 lb. ,, ,, ,, ,, ,, ,, 18 ,, ,, ,,
S_3, 60 lb. ,, ,, ,, ,, ,, ,, 27 ,, ,, ,,

Vegetative growth.

Visual differences appeared within five days of planting, when foliage of plants in the two highest salinity treatments became darker green. Plants in the non-saline treatment grew rapidly and were " soft ", whereas growth was " harder " and more retarded with increase in salinity (Fig. 1, top) and the oldest leaves became senescent earlier. These differences in growth rates were reflected in the estimated dry weights of vegetative aerial parts, but plants in the high salinity plots produced a more normal type of growth as the season advanced and treatment differences became much less apparent (Table 1). Excavations at the end of the season showed no marked

TABLE I.

Yield data for the 1956 experiment, based on 3 plants per plot, i.e. 3×6=18 plants per variety.

	Treatments				Significant groupings (P=0·05)
	S_0 (non-saline)	S_1	S_2	S_3 (most saline)	
Estimated dry weight (gm.) of shoots					
Ailsa Craig	490	478	355	288	
Potentate	263	198	167	157	
Total yields (kg. per plant)					
Ailsa Craig	4·5	5·0	3·9	3·5	S_0—S_3, S_1—(S_2. S_3)
Potentate	2·8	2·4	1·9	2·1	S_0—(S_2. S_3), S_1—S_2
Yields of Ailsa Craig (kg. per plant*)					
May and June	0·6	0·6	0·6	0·5	n.s.d.
July	2·2	2·4	1·5	1·2	S_0—(S_2.S_3), S_1—(S_2 S_3)
August and September ..	1·7	2·0	1·8	1·8	n.s.d.
Grading of Ailsa Craig (% of saleable fruit)*					
under 8 per lb.	27·8	19·1	6·5	1·5	
8-12 ,, ,, ...	58·5	57·0	54·6	53·1	
13-16 ,, ,, ...	10·4	20·8	34·3	40·4	
over 16 ,, ,, ...	3·3	3·2	4·6	5·0	
Mean weight of Ailsa Craig fruit (gm.)*..	52	50	44	41	S_0—(S_2. S_3), S_1—(S_2. S_3)
Saleable fruit (% of total) ..					
Ailsa Craig	98·8	99·6	97·1	87·2	
Potentate	97·4	98·6	87·5	75·1	
% of fruit with blossom-end rot (unsaleable)					
Ailsa Craig	—	0·1	2·6	12·7	
Potentate	—	0·2	12·1	24·7	
% of fruit with blotchy ripening (mostly saleable)					
Ailsa Craig	4·5	2·4	0·5	0·4	
Potentate	14·5	4·4	1·7	0·8	

* Detailed data are given for Ailsa Craig only ; results for Potentate followed similar trends.

differences in the total number of roots in different treatments or in the pattern of root distribution.

Fruiting.

Differences in total yield between treatments in the first month of picking were not as great as might have been expected from the early appearance of vegetative growth (Table 1), since fruit from plants in the more saline plots matured more quickly, but there were marked differences in yield between treatments during the month of July, when nearly half the Ailsa Craig and a third of the Potentate crops were harvested. The total number of fruits per plant was not markedly affected by the treatments but fruits were significantly reduced in size in the more saline plots.

Virtually all the fruits of both varieties in the most saline treatment were affected by blossom-end rot when the cropping season began, but progressively fewer of the later fruits were affected. The occurrence of blotchy ripening was highest in the unsalinized treatment, particularly for the variety Potentate.

Water.

The amount of water needed to maintain the soil near field capacity was markedly reduced at higher soil salinities (Table II), especially during the first part of the

Table II.

Water required to prevent moisture tension rising above 7 cm. mercury in any part of the rooting zone ; 1956.

Irrigation data	Salinity treatments			
	S_0	S_1	S_2	S_3
Number of applications ..	57	55	55	44
Total volume of water applied per plant (gallons)	32·1	27·6	22·6	21·0
Volume of water per plant to 22nd July (gallons) ..	23·4	19·5	14·8	13·3
Volume of water per plant from 22nd July to end (gallons)..	8·7	8·1	7·8	7·7

season. Salter found that moisture tensions fluctuated most rapidly at a depth of about 6 in. in his non-saline soil, where the greatest concentration of roots normally occurred, but the pattern of drying out was different in the salinized plots, where water was removed most rapidly from the deeper layers of soil during the middle of the season, at which time the shallower layers remained virtually at field capacity. The trend was reversed later in the season, when substantial amounts of salts had been leached from the surface to the lower layers.

Salinity.

Trends in salinity throughout the season are shown in Fig. 2. There was little change in the least saline plots but salinity fell off markedly at 4–6 in. in other treatments, with only minor fluctuations at 20–22 in. Salinity at 28 in. (not shown) increased a little in S_2 and S_3 plots as the season progressed although not to an extent which would indicate an important amount of downward leaching to that level.

PLATE I.

S_0 1956 S_3

S_0—G 1957 S_3+G

Fig. 1.

Top, 1956. Appearance of tomato plants in the non-saline plots (S_0) and most saline plots (S_3) on 10th May. Each pair of plants includes one of the variety Ailsa Craig (*left*) and one of Potentate. (*right*).

Bottom, 1957. A shoot of Moneymaker from the non-saline soil (S_0—gypsum) showing flat laminae and open posture ; and from the most saline soil (S_3+gypsum) showing wrinkling of laminae, curling of petioles and leaflets, and congested appearance of the shoot apex. Photographed 9th May.

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Successive samples to a depth of 60 in. at the end of the season confirmed that there had been no substantial movement of salts out of the rooting zone. The decline of salinity in the surface layers of soil can mainly be attributed to the downward movement of salts in the irrigation water but, despite this seasonal drift, different treatments remained distinct from one another throughout the season at any given depth.

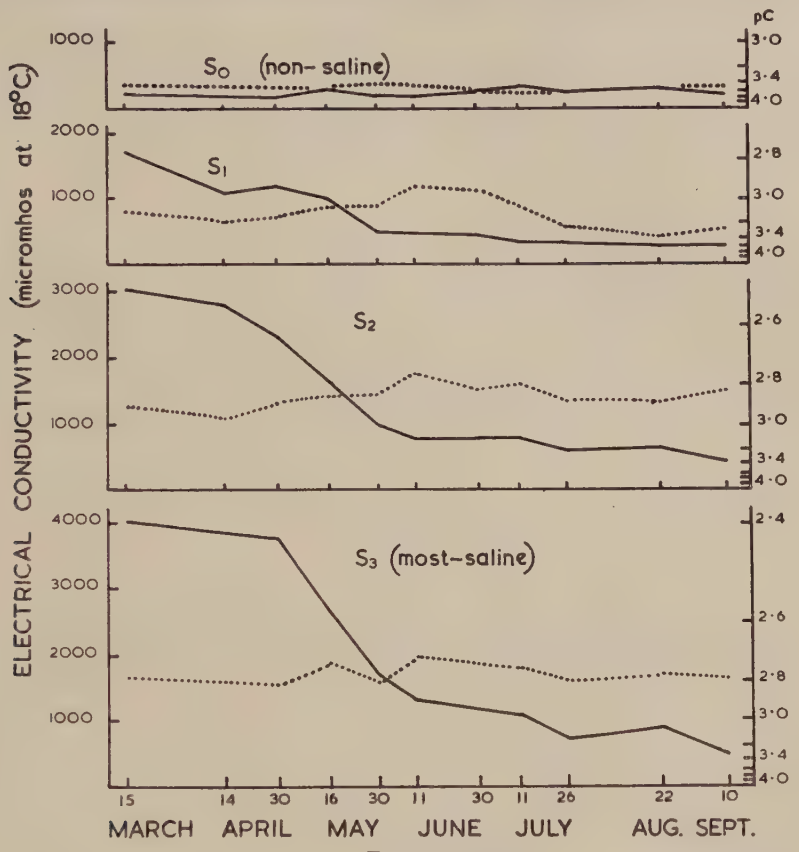

FIG. 2.

Electrical conductivities and pC values of soil samples taken at 4-6 in. (——) and 20-22 in. (····) at various dates during the 1956 experiment. Intermediate values were found at 6-8 in. at the beginning of the season.

Disease.

The incidence of *Botrytis* stem lesions was appreciably reduced in both varieties in the more saline soils but there was little difference in the incidence of attack by *Cladosporium fulvum.*

1957 EXPERIMENT.

Varieties : Ailsa Craig and Moneymaker.

Seed sown 15th January, 1957 ; seedlings pricked off 29th January, planted out 9th March ; main watering begun 30th March-4th April ; first fruits picked 16th May ; final recording 11th September.

In the 1956 experiment tomato plants were much affected in their growth and

cropping by the higher levels of salinity, but proved capable of recovering when salinity levels in parts of the active rooting zone fell during the growing season. In 1957 a similar experiment was carried out, but with a sub-treatment in which a heavy dressing of powdered gypsum (calcium sulphate) was added to half of the plots to ascertain the effects of this material, which is commonly present in large amounts in glasshouse soils and is said to depress yields.

The plots were not leached between the two experiments as the same layout was used and it was desired to retain the salts already present in the lower horizons so as to achieve a greater degree of uniformity down the profile after salinizing. Rather smaller amounts of the 3:1 potassium sulphate:magnesium sulphate mixture were applied as follows, in two waterings of 50 and 100 gallons to each plot :

S_0, no added salts
S_1, 10 lb. of salt mixture per plot
S_2, 25 lb. ,, ,, ,, ,,
S_3, 40 lb. ,, ,, ,, ,,

After salinizing, 22 lb. of powdered gypsum (approximately 10 tons per acre) was applied to three plots chosen at random in each treatment and thoroughly forked into the top twelve inches. This amount was sufficient to produce a saturated solution of calcium sulphate, both in the soil solution and also in the 1 : $2\frac{1}{2}$ soil : water suspensions at 4 in. but not at 20 in. deep (Fig. 3). Routine work was carried out as

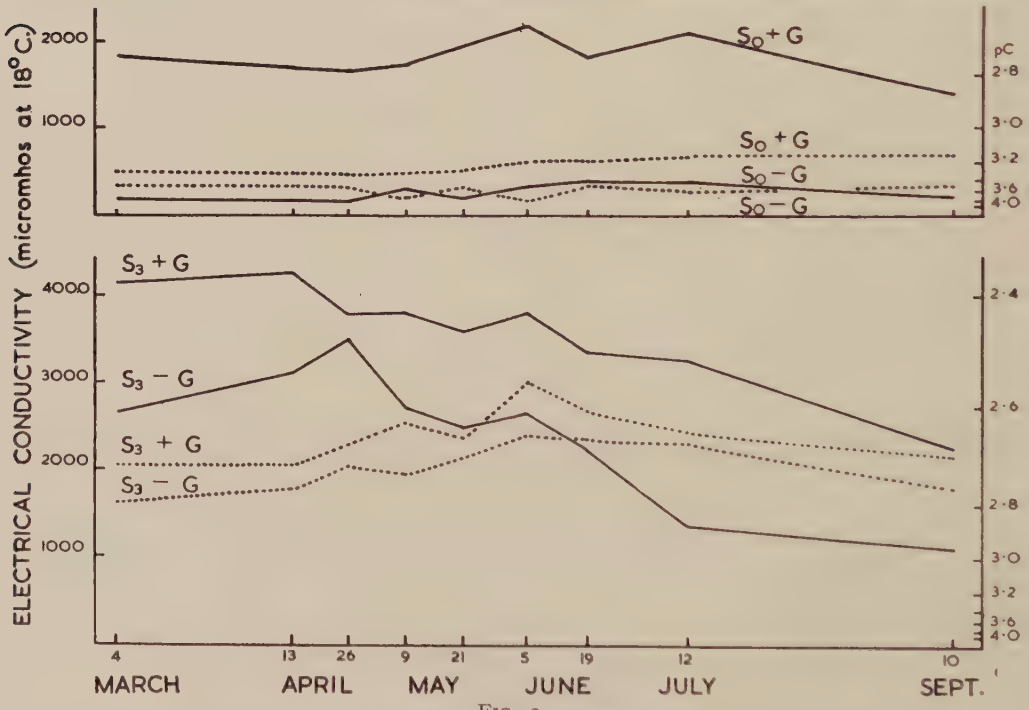

Fig. 3.

Electrical conductivities and pC values of soil samples taken at 4 in. (——) and 20 in. (· · · ·) at various dates during the 1957 experiment from the non-saline (S_0) and most saline (S_3) soils. ± G = with or without the addition of gypsum to the soil before planting. Curves for treatments S_1 and S_2, ± gypsum, were intermediate.

in the previous experiment, except that the amount of fertilizer was increased by using the nutrient solution at a concentration of 1 : 200.

Vegetative growth.

Differences in growth in the early stages were similar to those observed in 1956 (Fig. 1, bottom), but plants in the highly saline treatments did not recover later in the season. From July onwards many of the plants with a high incidence of blossom-end rot also showed symptoms of leaf scorch and the growing points of a number of plants died. The presence of gypsum had no marked effect on growth, a result similar to that of Winsor and Davies (1958) with lettuce and peas.

Fruiting.

Yields for August and September showed much wider differences between the extreme treatments than in 1956. The grading of fruit showed similar trends to those of the previous year, but a larger proportion of small fruit was produced and mean weights were small in all treatments (Table III). The net effect of gypsum over all

TABLE III.

Yield data for the 1957 experiment, based on 3 plants per plot, i.e. 3×3=9 plants per variety.

	No gypsum added				Gypsum added			
	S_0 (non-saline)	S_1	S_2	S_3 (most saline)	S_0 (non-saline)	S_1	S_2	S_3 (most saline)
Total yield (kg.) per plant								
Ailsa Craig	3·2	3·9	2·4	1·5	3·1	2·9	2·4	1·8
Moneymaker	3·0	3·4	2·2	1·4	2·8	2·6	1·8	1·7
Mean weight of all fruit (gm.)								
Ailsa Craig	36	36	29	17	31	33	25	21
Moneymaker	38	42	27	18	34	32	27	19
% of fruit with blossom-end rot								
Ailsa Craig	—	—	6·8	33·2	—	—	2·7	18·5
Moneymaker	—	—	8·6	31·4	—	—	4·0	27·5

Differences between ± gypsum are not significant for any level of salinity with either variety.
For salinity, significant groupings (P=0·05) are :
Ailsa Craig (S_0. S_1)—S_2—S_3, Moneymaker (S_0. S_1)—(S_2. S_3).

treatments was to cause a slight reduction in size of fruit compared with plots which did not receive gypsum. Blossom-end rot was even more prevalent in the two most saline treatments than in 1956, but appeared to be reduced in those high salinity plots to which gypsum had been added. Virtually no blotchy ripening was observed.

Water and salinity.

Rather less water was needed than in the previous year to maintain the soil at the predetermined tension of 7 cm. mercury. Considerable differences in weather, par-

ticularly in hours of sunshine, probably account for this difference and for the lighter yields in 1957.

Drifts in salinity again occurred but were less than in the previous experiment (Fig. 3), presumably because of the application of less irrigation water in 1957. The addition of gypsum increased the electrical conductivity readings, as was to be expected, but tended to mask the progressive reduction of salinity due to downward leaching of salts.

DISCUSSION.

Soils of many commercial glasshouses in Britain contain large amounts of soluble salts, mainly because fertilizers have been applied at annual rates often approaching 2 tons per acre (Owen, 1949), with resulting gradual accumulation of unused residues (Walsh and Clarke, 1945 ; Harper, 1955). This accumulation of salts has come to be recognized as one of the factors which contribute to the progressive reduction in yield of tomatoes that commonly occurs after the first few years in commercial glasshouses (McNaught, 1955).

When considering the effects of any particular burden of salts in a soil, due regard must be paid to the following points :

(*a*) Plants are affected by the nature and proportions of the salts which are present.

(*b*) The amount of available water removed during any drying cycle will affect the concentration of salts in the soil solution, and therefore the total soil moisture stress to which the roots are subjected. Thus the total stress may well be lower in a wet soil containing much salt than in a drier one with less salt.

(*c*) Soil texture affects the moisture holding capacity of the soil and, therefore, the lowest concentration which can occur in the soil solution for a given percentage of salts (Richards, 1954).

The present experiments were designed to reduce variations due to these factors to a minimum in each treatment, thus enabling a study to be made of the responses of tomatoes to different levels of salinity caused by a particular combination of salts which was chosen because of its relevance to conditions in old glasshouse soils.

A major difficulty in this type of work is to distinguish between the responses of plants to composition of the soil solution (ionic effects) and to its concentration (osmotic effects). Nicol (1957, 1959) and Heimann (1958) have, from different standpoints, suggested that the nature and balance of anions and cations in the soil solution exert important effects on plants quite apart from the well-known nutritional aspects, but the experiments here described were not designed to study that aspect. The ionic balance in treatments S_1—S_3 was presumably similar although, of course, the concentrations were very different. Thus differences between S_1—S_3 are more likely to have been caused by the effect of concentration rather than ionic balance. Treatments S_0 (both years) and + gypsum (1957) differed in ionic composition of soil solution from S_1—S_3 (both years), and thus might form the basis of comparisons, but yield differences between these treatments were not significant. It would be interesting to study the specific effects of ionic balance by subjecting plants to soil solutions with similar osmotic pressures (pC) but containing different salts.

A further difficulty is that the gradual fall in salinity of the upper soil in the salinized treatments makes interpretation of responses more difficult than if salinities

could have been maintained at constant levels, and the pattern of growth and yield at any given time must be considered in the light both of previous and prevailing salinity conditions. In 1956 weekly increments in estimated dry weight of plants in the extreme treatments (S_0 and S_3) showed that growth rates were of the same order in both treatments from the third week in June, by which time the electrical conductivity of the surface layer of the salinized soil (S_3) had fallen to a pC value of 2·9, whereas all soil in the non-saline treatment (S_0) had a pC value of about 3·7. The fresh weight of fruit picked per week from the non-saline and most saline treatments became of the same order in the second week in August, after which differences in yield until the final picking were non-significant. This suggests that development of fruits picked after mid-August was not affected by the treatments. Approximately sixty days elapse from the pollination of a flower to the ripening of a tomato fruit, and it can therefore be assumed that fruit picked after the first week in August would have commenced development at about mid-June, i.e. at about the time that vegetative growth ceased to show marked treatment differences. Fluctuations of tensiometer readings between irrigations in mid-June showed that water was being taken up most rapidly from the top six inches in S_3, where the pC value was about 2·9. If, as seems probable, the net effect of salinity on growth in a moist soil is dependent on the level of salinity in the least saline horizon occupied by the roots, it can be concluded that, under the conditions of the 1956 experiment, growth of tomato plants was not depressed provided that (*a*) at least part of the soil profile had a pC value of 2·9 or over and (*b*) the soil was maintained near field capacity and not allowed to dry out appreciably between irrigations.

In the 1957 experiment, two equally productive crops were grown in soils with pC values of approximately 3·6 and 2·7, where the lower value was due to the presence of gypsum, but yields were significantly less in soil with a pC value of the same order due to the presence of potassium and magnesium sulphates.

The buffering effect of sparingly soluble salts on the salinity values of soil suspensions makes interpretation of these values difficult without reference to the actual salts which are present. Various workers, including Richards (1954) and McNaught and Houston (1956), state that, where sparingly soluble salts are present, it is highly desirable that determinations should be carried out on soil suspensions with the lowest practicable ratio of water to soil, a conclusion that is borne out by the results of the present experiments.

The following conclusions can be drawn from the experiments described in this paper.

1. At a range of soil salinities, induced by the addition of a 3 : 1 mixture of potassium and magnesium sulphates, tomatoes grew equally well in all soils where the pC value for the least saline part of the root zone was above 2·9 (an electrical conductivity of about 1300 micromhos at 18°C.), provided that the soil was kept near field capacity (i.e. irrigated when soil moisture tension rose to 7 cm. mercury). If, however, soil was allowed to dry out more between irrigations, a lower degree of salinity would probably be critical.

2. The main effects in these experiments, especially between treatments S_1, S_2 and S_3, are believed to have been due to various degrees of physiological drought in soil solutions of high osmotic pressure, in spite of the fact that all the soil was maintained near field capacity throughout the experiments and roots never experienced dry conditions.

3. Tomato yield was not affected by the addition of gypsum, at the rate of 10 tons per acre to the top twelve inches of soil, at any level of salinity within the range tested in these experiments.

4. In considering salinity account must be taken of the effects of both osmotic pressure and ionic balance. It is not possible to distinguish between these effects in the experiments described, but the addition of gypsum, which altered the ionic status of the soil solution, had no significant effect on yields. Information on ionic balance is not, of course, revealed by assessments of pC values, which are based on the total effects of all the salts on the conductivity of a soil suspension.

5. There is weighty evidence that blossom-end rot is due to calcium deficiency in the fruits (Spurr, 1959), rather than to lack of water, as was thought by earlier workers. In the present experiment the application of excessive amounts of potassium and magnesium salts may have led to luxury uptake of these cations, with consequent depression in calcium uptake. The reduction in blossom-end rot in the gypsum plots could support the hypothesis that the disorder is due to lack of calcium.

6. The incidence of blotchy ripening confirms the well-known susceptibility of the variety Potentate to this disorder, and tends to support the conclusion of Butters (1956) that blotchy ripening is reduced at a pC of about 3·0, without any reduction in yield due to high soil salinity. However, the degree of salinity is probably only one of many factors affecting the incidence of blotchy ripening (Cooper, 1958).

7. The pattern of water extraction showed that, in any particular treatment, water was taken up most rapidly from the zones of soil where salinity was lowest.

SUMMARY.

Two experiments are described in which tomatoes were grown in brick-walled plots in a glasshouse, under moist water-regimes, but in soils brought to different levels of salinity by watering before planting with solutions containing various amounts of a 3 : 1 mixture of potassium and magnesium sulphates.

In 1956, four treatments giving a wide range of salinity levels indicated that growth and yield of tomato plants were depressed when the electrical conductivity of 1 : 2·5 (wt. : wt.) soil : water suspensions of soil samples rose above 1,300 micromhos per cm., that is, when the pC value fell below about 2·9.

In 1957 similar salinity treatments were used, with similar effects on growth and yield but, in addition, gypsum was added to half the plots at the rate of 10 tons per acre. The addition of gypsum did not significantly affect the yield of tomatoes.

Blossom-end rot was prevalent in soils at high salinity levels. Blotchy ripening was much more prevalent in the variety Potentate than in Ailsa Craig but was reduced as salinity increased. The highest yields of best quality fruit were produced at moderate levels of salinity.

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THE INFLUENCE OF DOLOMITIC LIMESTONE ON THE CATION RELATIONSHIPS IN LEAVES, BARK AND ROOTS OF CORTLAND APPLE TREES

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It has been shown that magnesium deficiency in apple trees may be corrected by the application of dolomitic limestone to the soil (2, 5, 10). Studies at Kentville, Nova Scotia (4) have further shown that such treatments, associated with trees high in nitrogen, resulted in the appearance of incipient potassium deficiency symptoms with foliar levels of less than 1%. These studies suggested that this condition was brought about by an antagonism between potassium and magnesium and a growth dilution effect induced by ample supplies of nitrogen.

The object of the present investigation was to study the effect of dolomitic limestone on the levels of potassium, magnesium and calcium in the apple tree, and the inter-relationship between these cations in various parts of the tree.

Materials and methods.

Material for this study was obtained from an experimental orchard of 23-year-old (in 1954) Cortland apple trees planted in sandy loam soil. The experimental layout has been described in detail (4). Two series, A and B, each consisting of five plots of three trees each were used, and these are detailed in Table I. The dolomitic limestone was applied every five years commencing in 1945.

Table I.

Influence of dolomitic limestone on the cation content of an orchard soil (1954).

Series	Annual treatment 1,000 lb./acre N P K	pH	Exchangeable m.e./100 gm. K	Mg	Ca	Cation exchange capacity m.e./100 gm.
A— No lime	0–0–0	5·2	0·33	0·31	2·20	13·93
	0–10–0	5·1	0·32	0·54	2·64	13·66
	0–0–5	5·1	0·39	0·18	1·36	12·61
	3–0–0	5·0	0·25	0·14	1·00	11·64
	16–0–0	4·6	0·25	0·09	0·56	12·05
	Average	*5·0*	*0·31*	*0·25*	*1·55*	*12·78*
B— Dolomitic lime 2 tons/acre	0–0–0	6·5	0·35	2·02	5·73	13·86
	0–10–0	6·2	0·34	1·43	5·35	14·57
	0–0–5	6·0	0·49	1·28	2·85	12·94
	3–0–0	6·3	0·39	1·74	4·96	14·82
	16–0–0	6·1	0·34	1·21	4·41	12·69
	Average	*6·2*	*0·38*	*1·54*	*4·66*	*13·78*

N, Percentage N_2 supplied in ammonium nitrate (33% N_2)
P, Percentage P_2O_5 supplied in superphosphate (20% P_2O_5)
K, Percentage K_2O supplied in muriate of potash (60% K_2O)

From 1954 to 1957 individual samples for analysis were taken from each tree during the second week of July. These consisted of 33 leaves from the mid-section of the current year's terminal growth and samples of bark from five 5-year-old branches. Roots 1·5 mm. in diameter or less were removed from the upper 6 in. layer of soil in the cultivated area directly below the outer branches. These roots were air-dried and the soil particles removed by sieving. All samples were dried at 71°C. for four hours and very finely ground. Total nitrogen was determined by a micro-Kjeldahl distillation method (1) and total phosphorus colorimetrically by amino-naphthol-sulphuric acid reduction (11). Total potassium, magnesium and calcium were determined by flame photometry (6, 8).

In 1954 composite soil samples representative of 0–6 in. depth were taken from the cultivated areas in each plot. Procedures given in *Chemical methods of soil analysis* (3) were followed in the determination of the exchangeable cations, potassium, magnesium and calcium. Methods given by Peech *et al.* (9) were followed in the determination of pH values and base exchange capacity.

Results.

Soil analysis.

The data in Table I show that, although there was a marked variation between the plots in the soil content of each of the exchangeable cations, the addition of dolomitic limestone was consistently associated with an increase of these cations, particularly magnesium and calcium.

Concentrations of cations.

The dominating influence of dolomitic limestone on the cation content of the leaves from trees differing in nutrient status is apparent from the data in Table II.

Table II.

Influence of dolomitic limestone on the cation content of apple leaves from trees of differing nutrient status (1954–57, inclusive).

Annual treatment 1,000 lb./ac. N P K	% dry weight (average of 3 trees)					
	K		Mg		Ca	
	No lime	Lime	No lime	Lime	No lime	Lime
0–0–0	1·50	1·24	0·14	0·23	0·86	0·60
0–10–0	1·50	1·10	0·12	0·21	0·79	0·68
0–0–5	1·83	1·52	0·13	0·19	0·81	0·56
3–0–0	1·34	0·95	0·15	0·28	0·71	0·57
16–0–0	1·31	1·00	0·15	0·22	0·68	0·57
Average	*1·49*	*1·16*	*0·14*	*0·23*	*0·76*	*0·60*

N, P, K: as in Table I.

Additions of dolomitic limestone were associated with a general increase in magnesium and decreases in the levels of potassium and calcium (Table III). These differences were most marked in the leaves.

With regard to the distribution of cations, the concentration of potassium was much higher in the leaves and that of calcium in the bark than in the other sampled parts of the tree. On the other hand magnesium concentrations were relatively uniform in the leaves, bark and roots.

Table III.

Influence of dolomitic limestone on the cation content of leaves, bark and roots of Cortland apple trees (1954–57, inclusive).

Cation	Unit samples	% dry matter		% increase or decrease
		No lime	Lime	
K	Leaves	1·49	1·16	(—) 22·2
	Bark	0·29	0·26	(—) 10·2
	Roots	0·39	0·33	(—) 15·4
Mg	Leaves	0·14	0·22	(+) 36·4
	Bark	0·11	0·17	(+) 35·3
	Roots	0·11	0·14	(+) 21·4
Ca	Leaves	0·77	0·61	(—) 20·8
	Bark	2·60	2·24	(—) 13·8
	Roots	0·65	0·61	(—) 6·1

Inter-relationships between cations.

The inter-relationships between the cations, expressed as correlation coefficients are given in Table IV. The correlation coefficients were obtained from the residual term in covariance analysis of the 5 pairs of values available from the plot means with the " between years " correlation eliminated.

Table IV.

Correlation coefficients of the cation contents of the leaves, bark and roots of Cortland apple trees (1954–57, inclusive).

Relationship	Treatment	Leaves	Bark	Roots
K—Mg	Without lime	−0·475	+0·319	+0·326
	With lime	−0·673*	+0·448	+0·553*
Ca—Mg	Without lime	−0·539*	−0·269	+0·217
	With lime	−0·042	+0·276	+0·183
K—Ca	Without lime	+0·444	+0·149	+0·092
	With lime	−0·064	−0·109	+0·001

* Significant at 5% level.

Although the coefficients are mostly non-significant, those shown for the leaves correspond very closely to similar observations previously reported (4). Thus the negative K/Mg relationships, unlike the others, were unaffected by the addition of

dolomitic limestone. The values shown for bark and roots in the " no lime " series are clearly different from the coefficients for the leaves and it will be seen that the potassium/magnesium relationship in the roots was positive in both series.

DISCUSSION.

The low concentrations of exchangeable cations found in the soil of the unlimed series of the experimental orchard (Table I) were reflected by the nutrient levels in the leaves of the Cortland apple trees (Table II). The average magnesium concentration was 0·14% which is considerably less than the critical level of 0·20% suggested by Boynton and Burrel (2). Calcium levels averaged 0·76% and these approximate to minimum levels found by Wallace (10). The level of potassium was close to 1·49%, which is considered to be within the desirable range (2).

The marked increases in exchangeable magnesium and calcium in the soil due to treatment were only reflected in the tree by higher concentrations of magnesium in the leaves, roots and bark (Tables I and III). This was in contrast to a general decline in levels of potassium and calcium and also to a slight decline in foliar nitrogen found in 1950–51 (4).

Under the conditions of this experiment it would seem, therefore, that the relatively vigorous appearance of the trees receiving dolomitic limestone was largely due to the increased uptake of magnesium.

The negative relationship found between potassium and magnesium in apple leaves in this study (Table IV), and in other investigations (2, 5, 10), does not hold true for the bark and roots. These findings support Lundegardh's statement (7) that the degree of ion antagonism in one organ of a plant is independent of the behaviour in another organ.

SUMMARY.

A four-year study of the cation content of the leaves, bark and roots of Cortland apple trees showed that addition of dolomitic limestone resulted in a general increase in the levels of magnesium and a decrease in potassium and calcium.

The established negative relationship between potassium and magnesium in apple leaves was not found in either the bark or the roots.

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THE EFFECTS OF PLANT FORM AND PLANTING DENSITY ON GLASSHOUSE TOMATO CROPPING

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In the growing of tomatoes in commercial glasshouses main stress is laid on highest yield per unit area. Yield per plant is dependent, among other things, upon the pruning treatment given and the competition between adjacent plants. The present contribution gives some relevant data on these aspects of yield for the variety Potentate, the variety which is believed to be the most widely cultivated in the United Kingdom.

Methods.

The seed was sown in John Innes seed compost, the seedlings potted up in 3½ in. pots in John Innes potting compost as soon as they were big enough to handle and planted out in the glasshouse border when the first truss was visible.

An attempt was made to ensure that soil moisture and soil nutrients were at no time limiting growth but it was not possible to be certain that the attempt was successful. Water and fertilizers were applied at weekly intervals uniformly over the whole glasshouse area, irrespective of the pruning or spacing treatments that were applied. A nitrogenous and a proprietary potash-phosphate compound fertilizer were each applied at the rate of 1 oz. per square yard each week from planting. The amount of water applied varied through the season, the criterion being that the soil throughout the house, as indicated by auger borings, should be very moist down to a depth of 3 ft., from the date of planting onwards. Fruits were picked daily at the normal commercial stage of maturity.

Results.

Effect of plant form on yield per plant.

Over a period of four years plants on which selected first order axillary shoots were allowed to develop (second order axillary shoots being removed) were compared with plants on which all axillary shoots were removed. Various patterns of selected shoots were compared but, in all years and with all patterns, the conclusions were similar : the retention of axillary shoots increased yield per plant, number of fruits borne and percentage of uniformly coloured fruits, but it decreased mean fruit weight. Consequently only the final experiment, in which the plant forms tested were most likely to be commercially applicable, will be described in detail.

In this trial, carried out in 1956, the axillary shoots retained were allowed unchecked growth until they reached the overhead supporting wires when the growing points were removed. The treatments were as follows :

Form A : Single-stemmed plants with all axillary shoots removed, the growing points being removed at the level of the overhead supporting wires.

Form B : As Form A, but with axillary shoots arising from leaves below the 1st inflorescence retained.

Form C : As Form B, but with the axillary shoots arising from leaves immediately below the 2nd–6th main stem inflorescences retained in addition.

Form D : As Form B, but with the axillary shoots arising from leaves immediately below all main stem inflorescences retained in addition.

These plant forms are shown diagrammatically in Fig. 1.

The sowing date of all the forms was the same, 22nd November 1955. The plants were grown 6 ft. apart in both directions and there were twenty replications of each plant form in a randomized block layout.

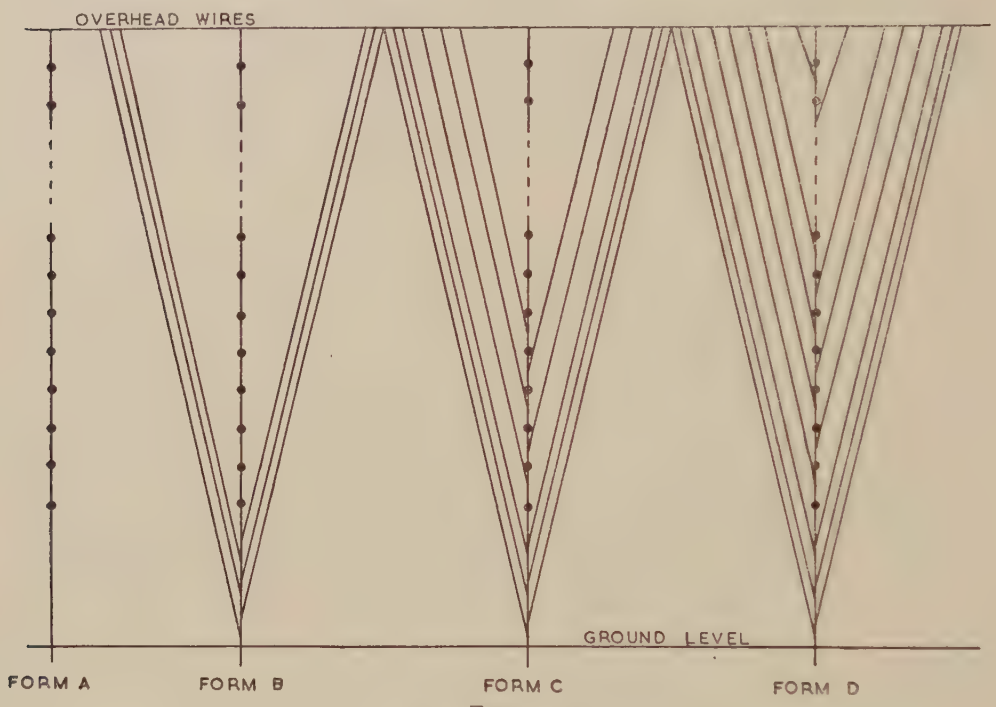

Fig. 1.
Plant forms A—D.

In Table I are shown the means per plant for yield, number of fruits picked, weight of individual fruits and percentage of uniformly coloured fruits.

Table I.
Cropping data for plant forms A, B, C and D.

Plant form	A	B	C	D
Yield (gm.)	16,458	49,278	50,120	50,405
Fruit number	204	750	776	803
Fruit weight (gm.)	81	66	65	63
Uniformly coloured fruits (%)	45	63	70	71

Relative to the single-stemmed form (A) the multi-stemmed forms B, C and D showed highly significant ($P=0\cdot01$) increases in yield per plant, number of fruits borne and percentage of uniformly coloured fruits ; there was also a highly significant ($P=0\cdot01$) decrease in mean fruit weight. There were no apparent differences between the three multi-stemmed forms in relation to yield, fruit number and mean fruit weight. The amount of uniformly coloured fruit produced was, however, affected, the multi-stemmed form with the least number of retained axillary shoots (B) producing a lower percentage ($P=0\cdot05$) than did the multi-stemmed forms with more axillary shoots (C and D). There was no apparent difference between Forms C and D in this respect.

This suggests that the increase in the percentage of uniformly coloured fruits may be related to the retention of axillary shoots, the greater the number of axillary shoots retained (up to a limit between Forms C and D) the greater the increase in the proportion of such fruits. An alternative interpretation would be that there is an inverse relation between uniformity of colouring and fruit weight. The small proportion of uniformly coloured fruits was the result of the very strict colour grading, any fruit having the slightest colour blemish being excluded. The most frequently occurring disorders were greenback and green blotchy ripening.

From the results so far described it can be concluded that, on a per plant basis, multi-stemmed plants contrasted with single-stemmed in producing a greater total weight of fruit with a smaller mean fruit weight and a greater percentage of uniformly coloured fruits.

From the practical point of view the fewer the axillary shoots retained the greater the ease of management. Since the differences in cropping between the three multi-stemmed plant forms were slight, the form in which only the laterals arising below the first truss were retained (Form B) could be regarded as the most suited to glasshouse cultivation.

Effect of plant form and planting density on yield per unit area.

To determine whether the increase in yield per plant from the multi-stemmed form represented an increase per unit area, multi-stemmed plants pruned as Form B were compared in 1957 with single-stemmed plants (Form A) at several planting densities.

Rows of single-stemmed plants with 2 ft., 3 ft. and 4 ft. between the rows were compared with rows of multi-stemmed plants at similar spacings. The former were spaced at 1 ft. apart within the rows and the latter at 4 ft., these being the closest intra-row spacings that were practicable. These plantings gave 288, 432, 576, 1,152, 1,728 and 2,304 sq. in. per plant, in the order as stated.

The rows were planted in a north-south direction in two adjacent 29 ft. wide and 100ft. long sections of a block of vinery-type houses. The areas of all treatment plots were identical, the plot size being 28 ft. × 14 ft. A randomized block layout was used and guard plants and guard rows were arranged so that all edge experimental plants had the same spacing on both sides.

An attempt was made to ensure that soil moisture and soil nutrients were supplied in excess of requirements so that the effect, if any, of spacing between rows would be one of competitive demand for light and not for soil. Water and fertilizers were

applied at weekly intervals uniformly over the whole experimental area, irrespective of plant spacing or whether the plants were single- or multi-stemmed.

Details of cropping are given in Table II.

Table II.

Cropping data for single- and multi-stemmed plants at three planting densities.

	Single-stemmed rows			Multi-stemmed rows		
	2 ft.	3 ft.	4 ft.	2 ft.	3 ft.	4 ft.
Yield (gm. per sq. ft.) ..	1,534	1,400	1,244	1,189	1,238	1,223
Fruit number per sq. ft. ..	33	30	27	24	23	23
Mean fruit weight (gm.) ..	45	47	45	48	52	53
Uniformly coloured fruits (%)	50	45	45	54	50	50

The single-stemmed plants at the close and intermediate spacings gave the greatest weight of fruit per unit area. All other treatments significantly ($P=0.05$) reduced the yield and there was no significant difference between them. Similarly the single-stemmed plants at the two closer spacings bore the largest number of fruits per unit area. Also, at the wide spacing, though they bore significantly fewer fruits per unit area than at the two closer spacings, they gave significantly more fruits per unit area than did any of the multi-stemmed treatments.

It was shown earlier that, when single-stemmed and multi-stemmed plants were compared individually at wide spacings, the retention of the axillary shoots was associated with a reduction in mean fruit weight. With the planting densities now being considered, the multi-stemmed plants at the two wider spacings bore fruit of mean weight significantly ($P=0.05$) greater than the general mean, whereas the mean weight of the fruit borne by the single-stemmed plants at all spacings was significantly lower than the general mean.

Thus, on a per plant basis, at very wide spacings multi-stemmed plants yielded more heavily than single-stemmed because of the larger number of fruits borne per plant and despite a relatively smaller fruit weight. On an area basis, at closer spacing the single-stemmed plants yielded more heavily for similar reasons, i.e. because of the larger number of fruits borne per unit area and despite a relatively smaller mean fruit weight.

At the very wide spacings of the earlier comparisons (Table I), single-stemmed plants gave a lower percentage of uniformly coloured fruits. At the closer spacings now being considered, the single-stemmed plants again yielded a significantly ($P=0.05$) lower percentage of uniformly coloured fruits except at the closest spacing. At this spacing there was no significant difference between the single- and multi-stemmed plants, although the former still tended to yield a lower percentage of uniformly coloured fruits.

For the single-stemmed plants there was a consistent trend of increasing yield with increasing planting density up to the highest, viz. one plant per 288 sq. in. with rows 2 ft. apart. It is a practical impossibility in tomato growing to reduce working paths to less than 2 ft. and, even at 2 ft., tending the plants is extremely difficult

Thus, to increase planting densities further, a double row planting pattern becomes necessary and the greatest feasible planting density under commercial conditions allows 252 sq. in. per plant, obtained by spacing plants 1 ft. apart in double rows 1 ft. apart with $2\frac{1}{2}$ ft. working paths between. To test the trend of yield with increasing density up to this ultimate limit, the double row planting giving 252 sq. in. per plant was compared in 1958 with one of 360 sq. in., obtained by having single rows of plants spaced 1 ft. apart in the row with $2\frac{1}{2}$ ft. between rows.

The rows ran north-south and the same cultural treatment as described earlier was given. The two planting densities were replicated three times in a vinery-type glasshouse 29 ft. wide and 100 ft. long. Each treatment plot occupied the same area and was provided with guard rows, there being 96 plants at 360 sq. in. and 144 at 252 sq. in. (excluding guard plants) in each plot. Details of cropping are shown in Table III.

TABLE III.

Cropping data for single-stemmed plants at two planting densities.

	Plot means	
	360 sq. in. per plant	252 sq. in. per plant
Yield (gm.)	258,483	262,168
Fruit number ..	4,885	5,404
Mean fruit weight (gm.) ..	53	49
Uniformly coloured fruits (%) ..	41	46

There was no significant effect of planting density on total yield. This was due to the fact that with increased planting density the increase in number of fruits produced per unit area was offset by a decrease in the mean weight of fruit. This decrease in mean fruit weight was significant at the 0·05 level of probability. The effect on fruit number was not significant but it approached significance very closely. There was no significant difference in the production of uniformly coloured fruit at the two planting densities.

DISCUSSION.

From the data presented it is apparent that when Potentate plants are grown at very wide spacing (6 ft. × 6 ft.) the retention of axillary shoots results in a considerable increase in yield per plant. This is due to the increase in the number of fruits borne per plant, despite an associated decrease in individual fruit weight.

At planting densities sufficiently great to be economic, single-stemmed plants give a greater yield per unit area than do multi-stemmed plants. This is because of the greater number of fruits borne per unit area, and despite an associated decrease in individual fruit size. There thus appears to be an interaction of planting density and plant form capable of reversing the relative superiority of the fruit size of single-stemmed plants at very wide spacing. On an area basis the cropping of single-stemmed plants is, nevertheless, superior to that of the multi-stemmed form.

A considerable amount of experimental work has been done on planting densities for single-stemmed tomatoes grown under glass and the literature has recently been reviewed (Cooper, 1958). Lamm (1956) using plantings giving 465, 387 and 310 sq. in. per plant and Nicolaisen and Fritz (1954) using plantings giving 698 and 465 sq. in. per plant found that the closer the spacing the greater the yield per unit area. Sheard (1959) found the same trend of increasing yield with increasing density at even closer plantings (638, 522, 406 and 290 sq. in. per plant). Green and Waid (1904), who included an amazingly close planting (576, 324 and 144 sq. in. per plant), also found that yield per unit area increased as planting density increased. According to Zimmerley (1919), decreasing the space per plant from 900 to 720 sq. in. increased the yield per unit area, but decreasing to 540 sq. in. gave no further increase. Hoffmann (1932), Seaton (1934) and Lockie and Butters (1956), however, reported optimal spacings for glasshouse tomatoes at 480, 784 and 450 sq. in. per plant respectively.

The conflicting results of the above workers suggest the possible existence of an interaction between planting density and manurial or watering treatment. It is possible that those workers who reported increased yield per unit area with increased planting density were applying adequate fertilizer and/or water to support the increased yields at the increased densities, whereas those workers who failed to obtain increased yields were not doing so. The existence of an interaction of manurial treatment, watering rate and planting density has not been adequately tested.

The data for Potentate reported above show a trend of increasing yield per unit area with increasing planting density up to 252 sq. in. per plant—the limit under commercial conditions. Because of the large area required in experimental work involving spacing treatments, it is difficult at the higher densities to demonstrate significant differences with increased planting density, since the increased yields so obtained are relatively small. The plantings at which marked increases in yield ceased to be obtained (in the region of 450 sq. in. per plant) are fairly close and consequently, from the practical point of view, the factors which limit yield as density of planting is increased are apparently not connected with inter-plant competition but with ease of management.

SUMMARY.

1. At wide spacing (6 ft. × 6 ft.) the retention of axillary shoots in the Potentate variety of glasshouse tomato increased yield per plant, number of fruits borne and percentage of uniformly coloured fruits, but it decreased mean fruit weight.

2. At closer spacings the retention of axillary shoots decreased yield per unit area and number of fruits borne, but it increased mean fruit weight and percentage of uniformly coloured fruits.

3. There was a tendency for yield per unit area of single-stemmed plants to increase with increased closeness of planting up to 252 sq. in. per plant, but above 450 sq. in. per plant marked increases in yield per unit area were not obtained.

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A MODIFIED-ATMOSPHERE SYSTEM FOR PACKAGES OF STORED FRUIT

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The use of polyethylene liners to restrict ventilation and reduce moisture loss from stored fruit was first suggested by Gerhardt (4) in 1955, and became a commercial practice in the pear industry. Nevertheless, several workers have found that the variable permeability of the earlier polyethylene films to gases resulted in concentrations of carbon dioxide and oxygen which were injurious to fruit (5, 6). The writer (2) found that soda lime and the replacement of the internal atmosphere with nitrogen reduced CO_2 injury to apples. It was also observed that excessive amounts of moisture accumulated inside the liner.

The object of the present study was to find an effective method of maintaining an atmosphere containing 5% CO_2 and 3% O_2 within plastic packages and also to remove excess moisture which is conducive to fungal decay. The development of the dry scrubber for the removal of CO_2 from controlled atmosphere storages (3) suggested that plastic materials impermeable to CO_2 and O_2 could be used.

Materials and methods.

Plastic bags with a capacity of 2·7 cu. ft. were made from sheets of polyethylene terephthalate film,* 1 mil in thickness, which is impermeable to CO_2, O_2 and moisture. All seams were sealed with polyethylene terephthalate : aluminium foil lamia tape and each bag was inflated for one hour to test for leaks. The bags were equipped with glass sampling tubes and analysis of the internal atmosphere was made with modified Orsat apparatus.

The bags, henceforth referred to as " containers", when filled to capacity held 55 pounds of fruit and, although the free air space was not calculated, as much as possible was provided in order to prevent the development of negative pressures. These pressures may arise on the removal of gas samples (100 c.c.) and by the absorption of O_2 by fruit when there is no compensating accumulation of CO_2. Samples were therefore limited to 30 pounds of top-grade fruit in each package. For carbon dioxide absorption, a small bag (" insert ") of the same plastic film filled with one pound of fresh hydrated lime was laid on top of the apples in the container. Gas diffusion holes were made in the insert with a pin having a cross sectional area of 0·45 sq. mm. For moisture absorption a similar polyethylene insert pierced with $\frac{1}{4}$ in. holes and filled with calcium chloride (technical grade) was included (see Fig. 1). Similar holes were made in the walls of the containers for the O_2 supply.

The first series of tests was conducted with McIntosh Red apples which had been stored at 0° C. for 55 days. Three packed containers were placed at 3·5° C. Two of these contained both CO_2 and moisture absorption inserts, the third lime only.

* 'Mylar' polyester film, made by Dupont Co. of Canada (1956) Ltd.

The desired concentrations of CO_2 were obtained by making, within an area of 1 sq. inch, perforations through the wall of the container and into the lime. The holes in the container were then immediately sealed off with tape to prevent the ingress of oxygen to the fruit. Another three packed containers were stored at 21° C. but with lime only. The fruit stored at 3·5° C. was examined after 147 days and that at 21° C. after 50 days.

The second series included both McIntosh Red and Delicious apples which had been stored at 0° C. for 147 days. Three containers of each variety of apples were placed at 0° C. and 3·5° C. The fruit was examined after 75 days.

Control samples consisted of bushel boxes (approx. 40 pounds) of apples stored in air.

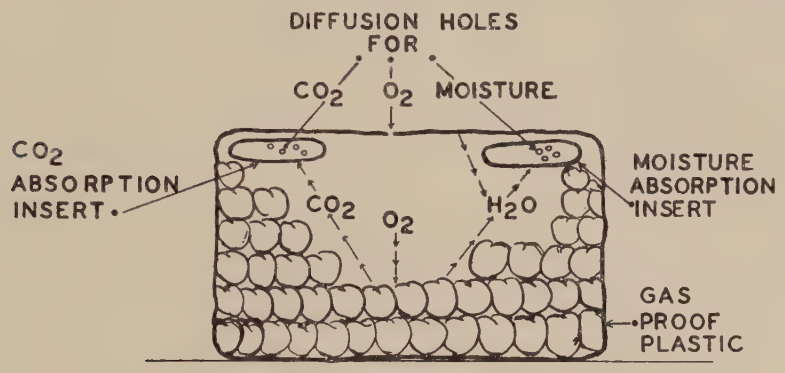

Fig. 1.

Package in modified-atmosphere container.

Examination of the fruit included Magness-Taylor pressure tester readings on two pared sides of 10 apples. The percentage of fungal rots and functional disorders and the moisture conditions within the bags were also noted.

Results.

Series 1.

The levels of CO_2 and O_2 in two containers at 3·5° C. are shown in Fig. 2, the third one having been discarded because of leaks. During the first few days there was a rise in the CO_2 concentration in both. This was curtailed when the atmosphere was allowed to diffuse into the lime insert by means of the holes which were made for that purpose. In order to maintain the CO_2 at between 4·0 and 6·0%, seven perforations were made. These provided a total diffusion area of 3·15 sq. mm.

There was a striking difference between the containers with and without calcium chloride in that the latter contained a heavy moisture deposit on the internal surfaces. This was associated with a relatively high percentage of fruits affected with fungal rots (Table I). Only the calcium chloride within one-half inch of the diffusion holes was affected by moisture.

Only two containers at 21° C. proved to be satisfactory. However, these gave identical results. The gas concentrations obtained and the number of perforations made are shown in Fig. 3. To maintain the CO_2 at 8%, nineteen holes were required

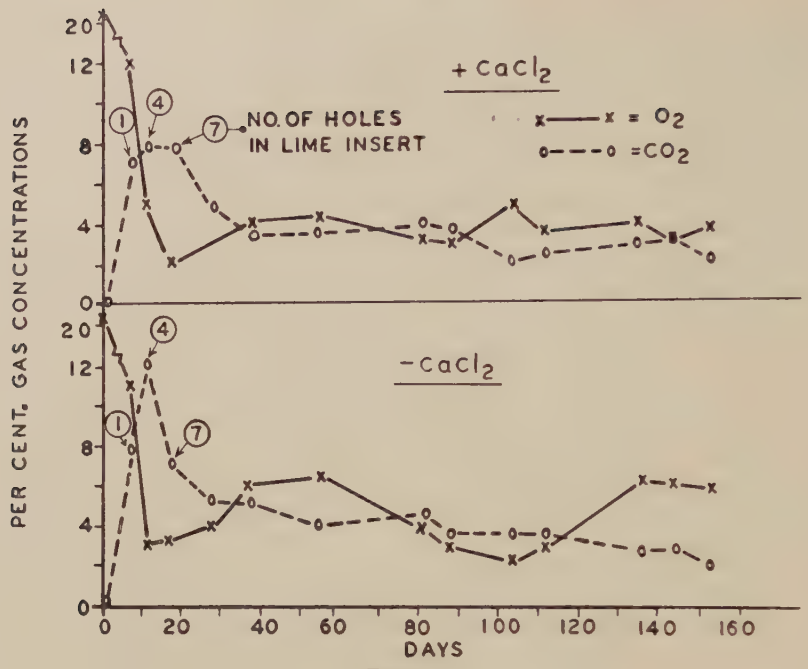

FIG. 2.

Carbon dioxide and oxygen concentrations in modified-atmosphere containers; McIntosh Red, 3·5° C.

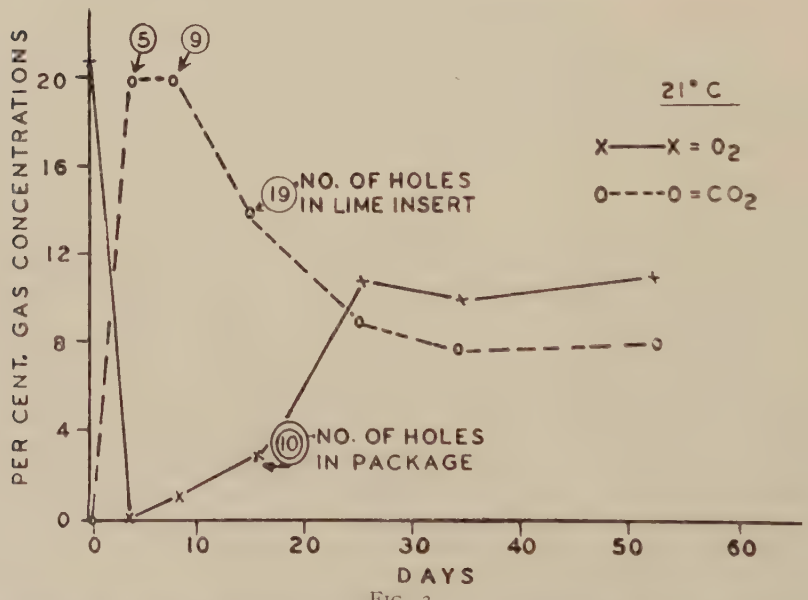

FIG. 3.

Carbon dioxide and oxygen concentrations in modified-atmosphere containers; McIntosh Red, 21° C.

in the lime insert. The O_2 levels fell to almost zero 2 days after sealing and negative pressures developed. Relief of these pressures during the first gas analysis caused a

TABLE I.

Keeping quality of McIntosh Red apples stored in plastic modified-atmosphere containers at 3·5° C. Examined after 147 days.

Chemicals included	Firmness lb. press.	% rot	% core flush	Flavour	Remarks
$Ca(OH)_2$ 1 lb.	10·9	31·6	10·0	Good	Heavy moisture on inner wall of bag
$Ca(OH)_2$ 1 lb. + $CaCl_2$ 1 lb. ..	12·5	14·5	0·0	Fair	No moisture
$Ca(OH)_2$ 1 lb. + $CaCl_2$ 1 lb. ..	11·0	13·5	6·0	Fair	No moisture
Control	—	68·0	100·0	Nil	

rise in O_2 content. On the fifteenth day the O_2 level was still low and 10 perforations were made in the wall of the container. The concentration then rose to 11·0%.

Series 2.

In this series the lime inserts were perforated with seven holes at the beginning of the experiment. No calcium chloride was added, as the main concern was the maintenance of the desired concentrations of CO_2 and O_2. The results shown in Figs. 4 and 5 are obtained from one representative container at each temperature.

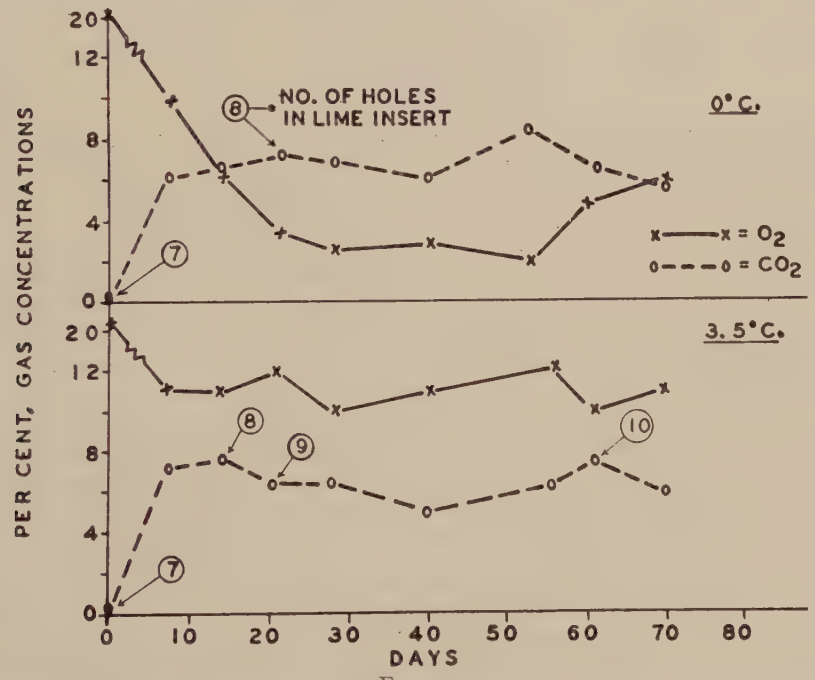

FIG. 4.

Carbon dioxide and oxygen concentrations in modified-atmosphere containers; McIntosh Red, 0° and 3·5° C.

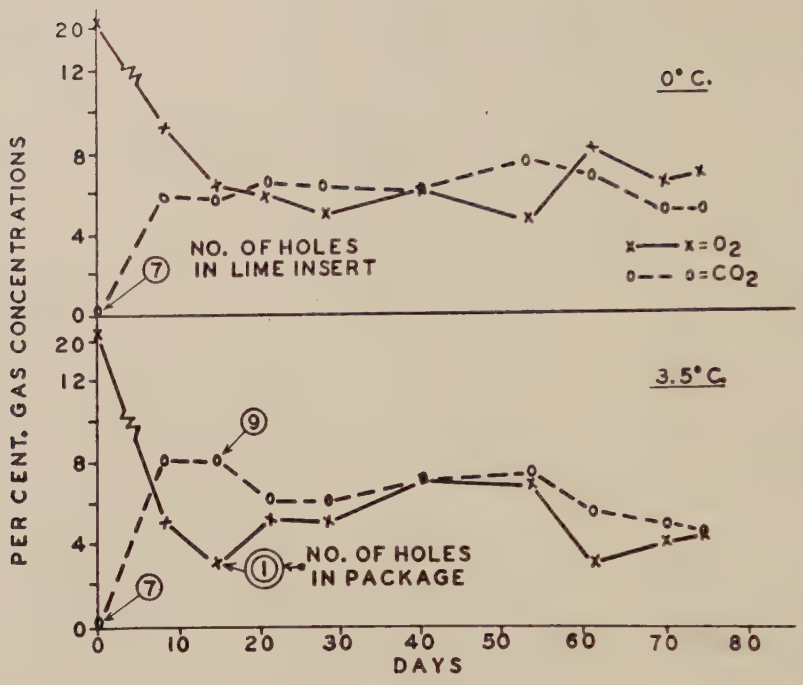

FIG. 5.

Carbon dioxide and oxygen concentrations in modified-atmosphere containers; Delicious, 0° and 3·5° C.

The CO_2 levels in the McIntosh Red samples were maintained at approximately 7·5% at both 0° and 3·5° C. with 8 and 10 holes in the respective inserts (Fig. 4). The O_2 content at 0° C. levelled off at 3% but rose to 6·6% towards the end of the trial. The concentration at 3·5° C. averaged approximately 11%.

With the Delicious apples the concentrations of CO_2 and O_2 ranged between 4·0 and 7·0% both at 0° C. and at 3·5° C., with 7 and 9 holes in the respective inserts (Fig. 5). One perforation was made in the container at 3·5° C. and this resulted in an increase in the O_2 concentration.

When the hydrated lime was titrated with standard acid at the conclusion of this experiment it was found that approximately one-half had become carbonated at 3·5° C.

Both varieties of apples in the containers were firmer and had less fungal rots than those stored in air (Table II). The McIntosh Red apples developed less core flush, but there was more scald on the Delicious at 3·5° C. in relation to the controls in air. The latter variety showed more breakdown in the containers than in ordinary air at the same temperature.

DISCUSSION.

These preliminary trials provide a new approach to the problem of modifying the atmosphere in small containers. The results indicate that a reasonable degree of reproducibility can be obtained by this method.

TABLE II.

Keeping quality of McIntosh Red and Delicious apples stored in plastic modified-atmosphere containers at 0° and 3·5° C.

Variety	Conditions of storage	Condition of fruit after 75 days storage Average of 3 containers					Remarks
		Firmness lb. press.	% rot	% core flush	% breakdown	% scald	
McIntosh Red	0° C. containers ..	10·0	11·7	25·0	—	—	Heavy moisture
	0° C. control (in air) ..	9·0	18·9	100·0	—	—	
	3·5° C. containers ..	9·7	25·5	50·0	—	—	Heavy moisture
	3·5° C. control ..	9·0	68·0	100·0	—	—	
Delicious	0° C. containers ..	15·1	0·0	—	9·0	0·0	Heavy moisture
	0° C. control ..	14·6	2·0	—	6·0	0·0	
	3·5° C. containers ..	14·2	4·5	—	0·3	22·3	Slight moisture
	3·5° C. control ..	14·8	10·0	—	0·0	12·0	

In order to maintain the desired level of CO_2 in the container, the relationships between temperature, CO_2 production by the stored material, and the area of diffusion governing the absorption of the gas by the lime insert must first be established. Other factors, such as the condition of the product when placed in storage and varietal susceptibility to functional disorders and fungal organisms, must also be considered. As regards varietal characteristics, the high percentage of fungal rots in McIntosh Red relative to Delicious apples has been noted (Table II).

It was found that, to maintain low levels of CO_2 within the containers at 3·5° C., a diffusion area of approximately 3·15 sq. mm. was required in the lime inserts, in contrast to 8·55 sq. mm. at 21° C. The temperature coefficient for respiration of apples in this range of temperatures in the post-climacteric stage of senescence is known to be approximately 2 (1). This suggests that the area for diffusion might possibly be based on such a relationship.

In the second series it was found that almost half the hydrated lime was carbonated during the 75 days of storage. However, recent work with the dry scrubber (3) showed that one pound of fresh hydrated lime was sufficient in tests with a 1,000 bushel controlled-atmosphere store.

Concentrations of O_2 were more difficult to control, since at sampling it was necessary to withdraw 100 c.c. of the internal atmosphere, which in turn was replaced by outside air. This periodic infusion of fresh air eliminated any necessity to ventilate the containers, except for McIntosh Red at 21° C. and Delicious at 3·5° C.

The O_2 concentration in the containers at 21° C. fell very rapidly but rose again after the first gas analysis (Fig. 3). The ten perforations made were excessive in that the levels were maintained at 11·0 % instead of the desired 3·0 %.

The addition of calcium chloride appears useful in reducing excess moisture, with an attendant reduction in fungal wastage (Table I). There was no visible shrinkage of the fruit with this treatment, and it was observed that only the calcium chloride within half an inch of the holes was affected by moisture, indicating that only a small amount of the absorbent is required to remove the excess moisture.

The modified-atmosphere system described in this paper appears to offer greater versatility than the polyethylene liner for storing small packages of fruit. This system is independent of the permeability to CO_2 and O_2 at a given temperature.

SUMMARY.

A method is described for the maintenance of modified atmospheres in gas-proof plastic containers for the storage of fruits.

Perforated bags of fresh hydrated lime and calcium chloride were inserted to regulate the CO_2 and moisture content respectively and the O_2 supply was maintained by perforations in the wall of the container.

Studies with McIntosh Red and Delicious apples indicate that it is possible to maintain desirable gas concentrations at 0°, 3–5° and 21° C. The removal of excess moisture with calcium chloride was associated with a reduction in fungal wastage.

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THE UPTAKE OF METALLIC IONS BY LEAVES OF APPLE TREES

I. THE MAGNESIUM CONTENT OF UNTREATED LEAVES

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Solutions containing metallic ions are commonly applied to fruit trees to remedy nutritional deficiencies or because of their toxic action on pests or diseases. In the latter use, the problem is to avoid toxicity to the host caused by entry of the metallic ions ; in the former, such entry is utilized to effect rapid improvement in the nutritional status of the tree. The conditions under which such materials enter the leaves of a treated plant are therefore of considerable interest.

Many studies of the foliar absorption of a wide range of materials have been made, mainly using radioactive tracer techniques, and the literature on the subject has been reviewed recently, notably by Boynton (1954), van Overbeek (1956), and Wittwer (1958). In the work to be described, attention has been confined to a small number of metallic elements and to the conditions under which they are taken up when compounds containing them are applied to apple leaves.

The use of foliar sprays for the rapid elimination of symptoms of magnesium deficiency in apple trees has been practised for some years. Magnesium sulphate applied as a soil dressing produces only slow results and, according to Hill and Johnston (1940), the full effect in the orchard occurs only after 2 to 3 years. In a study of the effect of added magnesium on the growth of MM.102 rootstocks in a stoolbed, Ford (1958) showed that a soil application of 16 cwt. of hydrated magnesium sulphate per acre, spread over three years, slightly reduced foliar symptoms after the second year and caused improved growth after the third ; on the other hand, a 2% spray applied nine times per year completely controlled leaf symptoms in the first year and led to increased growth in the second. It was therefore desirable to determine the uptake of magnesium from solutions of its salts applied directly to leaves of apple trees, particularly as there is little such information in the literature. By applying known quantities of various magnesium salts in solution to the lower surface of McIntosh Red apple leaves and measuring the amount left after various times, Fisher and Walker (1955) showed that magnesium was taken up by leaves most readily from nitrate and chloride solutions, least readily from sulphate and phosphate, and at an intermediate rate from acetate. Bukovac and Wittwer (1957) showed that, when a solution of a salt of the radioactive isotope Mg^{28} was applied to the leaf of a bean plant, magnesium was readily taken up and appreciable amounts were transported from the site of application to adjacent leaf tissue, but export from the treated leaf was negligible. Using 5% magnesium sulphate sprays, Oland and Opland (1956) showed that young apple leaves took up magnesium readily ; old leaves absorbed very little or nothing at all if sprayed during the day, but when sprayed just before darkness they absorbed large amounts. There was no indication from this work that magnesium absorbed by the leaves was carried away to other parts of the plant. It would thus appear that magnesium is readily taken up from a foliar application, but that, once taken up, it is not mobile within the plant. How-

ever, according to Wallace (1951), it is mobile within the (untreated) plant, and Phillis and Mason (1942) have shown that there is a diurnal variation in the magnesium content of the cotton plant, magnesium moving into and out of the leaves from and to the rest of the plant. If such a variation were to exist in the apple tree, it would have a complicating effect on measurements of uptake from foliar sprays. In this paper a study of the fluctuations in the magnesium content of untreated apple leaves, as a necessary preliminary to determining the uptake of this metal from foliar sprays, is reported.

Materials and methods.

A closely planted row of M.III rootstocks, grown on land which received hydrated magnesium sulphate at the rate of 3 cwt. per acre in 1956 and 1957, and 6 cwt. per acre in 1958, provided large numbers of upright stems annually. The experiments to be described were performed with some of these in July and August 1958.

Where leaves were to be treated with magnesium sulphate solution, six shoots, chosen at random, were labelled above the third and below the eighth fully expanded leaf, counting down from the tip of the shoot. At the appropriate time, one leaf from each shoot, selected according to a 6×6 Latin square design, was removed to make up a set of untreated controls, and then each shoot was bent over and dipped in a polythene bag containing magnesium sulphate solution with added Triton X-100 (a non-ionic wetting agent) at 0·02%, so that all the leaves to be treated were immersed. The polythene bag was then removed and the shoot allowed to return gently to its natural position, so that excess solution was not splashed on to the rest of the hedge. On each of five occasions subsequent to dipping, a set of six leaves was removed, one leaf being picked from each shoot according to the Latin square design. After picking, leaves were individually given two successive washes with 20 ml. of tap water and then mounted on a wire. Later they were brought back to the laboratory, dried overnight at 80°C. and, after cooling, weighed, ashed, and the magnesium content of the ash determined colorimetrically by a modified Titan Yellow method (Allen, 1960a).

Results.

First experiment.

This was designed to examine changes in the magnesium content of treated and untreated leaves. Leaves from positions 3–8 (inclusive) on eighteen shoots arranged in three 6×6 Latin squares were used, and each set of leaves from the first six shoots and the first set from each of the other two groups of six shoots were picked untreated. In each of these the remaining five sets were dipped in 2% magnesium sulphate solution and subsequently removed at the times shown in Table 1.

Table I.

Times of dipping and removal of leaves in first trial.

Group of six shoots	Dipped at: (hours)	Sets of leaves removed at: (hours)					
1. (Control)	—	10.10	11.00	11.45	13.15	15.00	16.10
2.	10.51	10.50	11.10	11.50	13.10	14.15	16.05
3.	13.16	13.15	13.35	14.10	15.05	16.00	16.45

An analysis of variance carried out on the magnesium contents of leaves of the untreated group showed that there was a highly significant difference in leaf magnesium content with time ($P<0.001$). The results, shown in Fig. 1, are expressed in terms of magnesium as a percentage of the dry weight and were obtained by dividing the mean magnesium content per leaf at a given time by the overall mean dry weight of the 36 leaves ; they are expressed in this way so that more meaningful comparisons between experiments can be made. In the first hour after dipping the shoots of the second group of six, there is a considerable rise in the magnesium content of the leaves ; in the absence of a suitable experiment involving untreated leaves, it

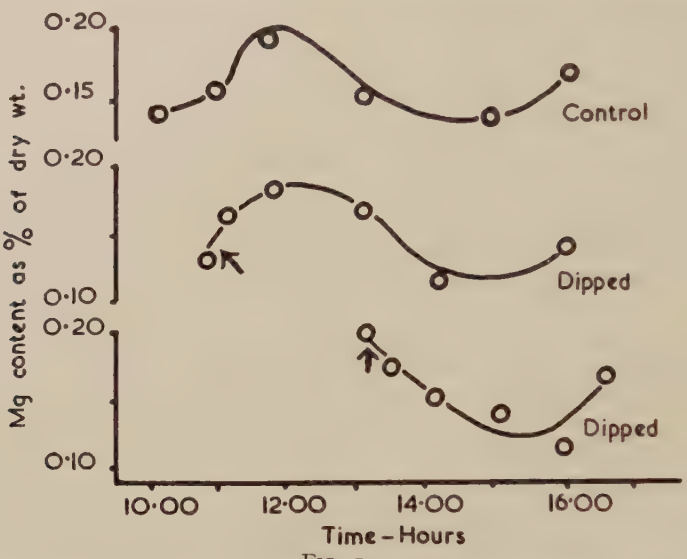

Fig. 1.

Changes in magnesium content of untreated leaves, and of leaves treated with 2% magnesium sulphate solution at the times indicated by the arrows.

might have been concluded that this rise was due to the treatment. But a consideration of the general shape of the curves corresponding to the three comparisons shows that, for dipped leaves, the change in magnesium content which would have occurred naturally is being measured rather than any change due to dipping the leaves in magnesium sulphate solutions. Thus, any results obtained without taking adequate untreated controls throughout the course of the experiment must, with this material, be regarded as useless. That such changes in untreated leaves do not invariably occur is evident, however, from the fact that in six experiments ranging in duration from 3 hours to 22 hours no significant change was found, whereas in seven experiments covering the same period significant differences ($P<0.05$) were recorded.

Second experiment.

To obtain further information on the movement of magnesium in untreated shoots, a set of six was chosen at random and removed from the row at each of the following times : 14·10, 14·40, 15·10, 15·40, 16·15, and 16·45 hours. Each shoot

was cut off just below the 9th leaf position and the tip (everything above but not including the first fully expanded leaf) and all expanded leaves were immediately removed and stored on a wire. Tip, leaves, and denuded stem were dried overnight at 80°C. and weighed, the stem being divided into three parts by cutting just below the 3rd and 6th leaf positions. The tip, 3rd, 6th, and 9th leaves, and the three segments from each stem were ashed and their magnesium contents determined. The results (Fig. 2), are expressed in terms of magnesium per leaf, or magnesium per internode, so that stem and leaves can be compared. There is a significant correlation ($P<0\cdot001$) between the magnesium content and dry weight of leaves; the dry weight did not vary significantly between leaves picked on the various occasions, and an analysis of covariance showed that there were significant differences in leaf magnesium between the various occasions ($P<0\cdot05$) and between the magnesium content of leaves at different positions ($P<0\cdot001$). More accurate estimates of the mean

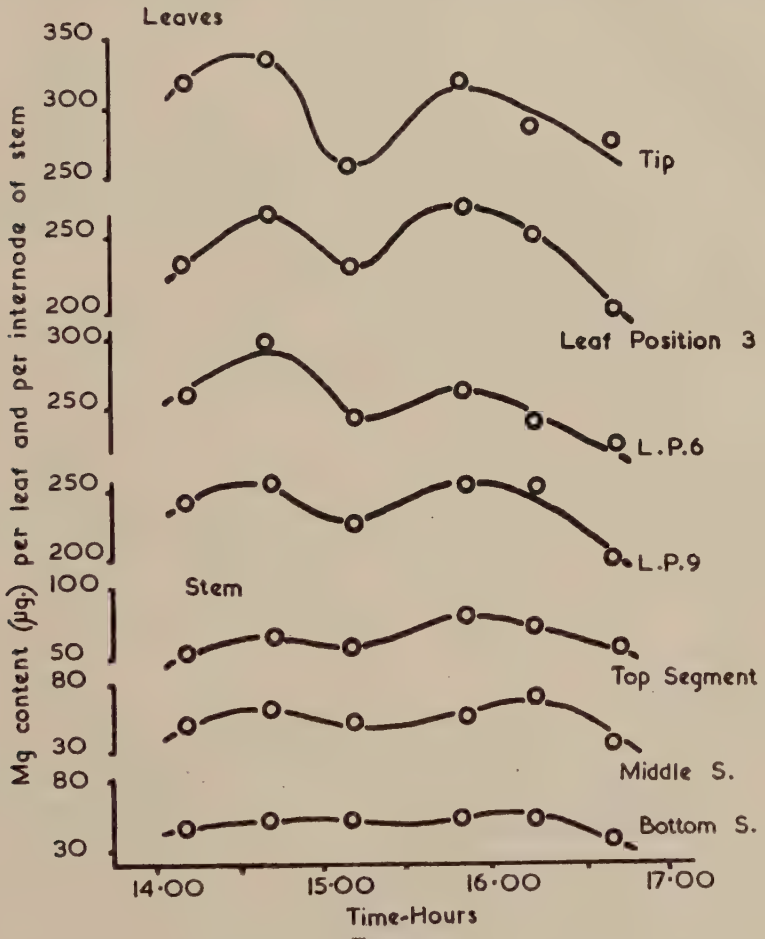

Fig. 2.

Magnesium content of leaves and stem collected from various positions on shoots of M.III rootstocks, at different times during an afternoon.

magnesium per leaf were obtained from an analysis of covariance for each leaf position separately ; these values are used in Fig. 2. In the stem, there is a highly significant correlation ($P<0{\cdot}001$) between the amount of magnesium in a segment in a given position and the dry weight of the latter, but the regression coefficients are different for the three stem positions, the equations being : top segment, $Mg=2{\cdot}00x-41$; middle, $Mg=1{\cdot}17x-84$; bottom, $Mg=0{\cdot}508x-31$; where Mg is the weight of magnesium (in micrograms) in a segment of stem weighing x milligrams. A separate analysis of covariance was therefore carried out for each of the three stem positions, and it was shown that for each of them the amount of magnesium in the stem did not vary significantly with time. Even so it will be seen, on comparing the results for stem and leaves, that the same pattern of behaviour holds for both and there is, in fact, a correlation between the amounts of magnesium in a leaf and in the segment of stem immediately below ; for the leaf position 3 and the middle stem segment, $r=0{\cdot}72$ ($P<0{\cdot}001$), and for leaf position 6 and the bottom stem segment, $r=0{\cdot}40$ ($P<0{\cdot}05$).

Fig. 3 shows the mean magnesium contents for the various leaf positions and stem segments over the whole experiment ; the magnesium content expressed as a percentage of the dry weight of leaf or stem is also given. The mean dry weight of leaves hardly varies over the positions, the values for the tip, 3rd, 6th, and 9th leaf positions being 0·153, 0·157, 0·166, and 0·165 gm. respectively. With the stem, however, the dry weight markedly changes with position, the figures for top, middle, and bottom segment being 0·116, 0·215, and 0·358 gm. respectively. In spite of this large change, the magnesium content scarcely changes in moving from the top to the bottom segment, and over most of the shoot a leaf contains about five times as much magnesium as the internode of stem associated with it.

Since the magnesium contents of leaves and stem rise and fall together, it follows that magnesium is flowing into or out of that part of the stem, from or to the rest of

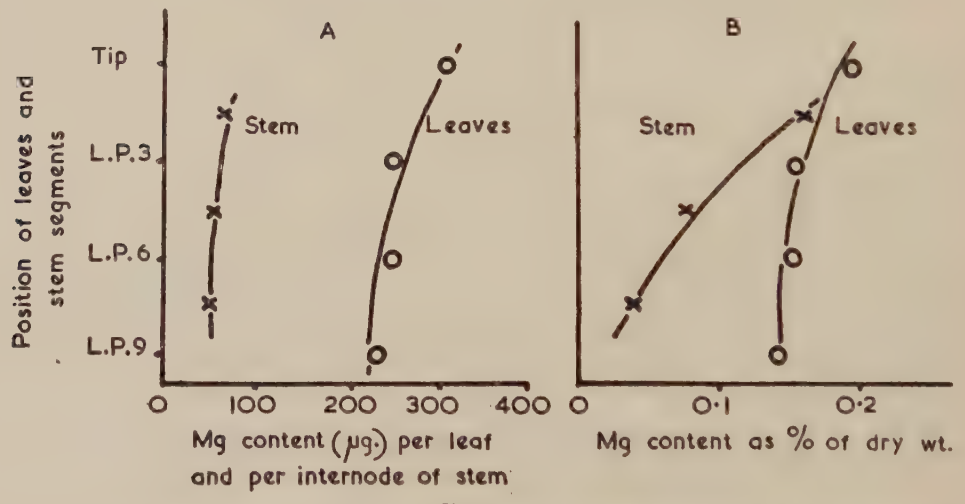

FIG. 3.

A. Relationship between magnesium content and position on the shoot of leaves and stem segments of M.III rootstocks.

B. Relationship between magnesium content, expressed as a percentage of the dry weight, and position on the shoot of leaves and stem segments of M.III rootstocks.

the plant. The bulk of it is going to the tip of the shoot and the leaves, but there is also a gradual increase in the amount of this mobile magnesium in the stem towards the tip. Thus, changes in the natural magnesium content of leaves, which must be allowed for when measuring uptake from foliar applications, seem to be smaller in older leaves. The way in which allowance for these changes can be made is illustrated in the next experiment.

Third experiment.

Leaves were used from positions 3–8 (inclusive) of twelve shoots arranged in two 6×6 Latin squares (treatment and control). One set of leaves was picked from each group of six shoots at the following times : at 9·55, 10·15, 11·30, and 16·35 hours on the first day, and 9·15 hours on the second and third days. Shoots of the treated group were dipped in 2% magnesium sulphate solution immediately after the first set of leaves had been picked. The results (Fig. 4) were statistically analysed by

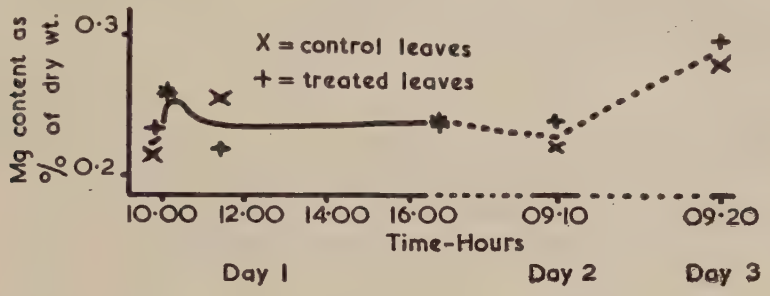

Fig. 4.

Changes in magnesium content of control leaves, and of leaves treated with 2% magnesium sulphate solution, immediately after picking the first set of leaves.

considering control and treated groups together and examining the interaction between " occasion 1 *v.* occasions 2–6 " and " treatment *v.* control ". This term was not significant ($P>0·2$), showing that in the treated group the change in magnesium content between the first and subsequent sets of leaves was not different from that in the control group. In this experiment leaves dipped in 2% magnesium sulphate solution showed no increase in magnesium content, as compared with untreated leaves, over a two-day period.

Fourth experiment.

The final experiment was designed to examine the effect of leaf position on the variation in magnesium content of controls, the residual errors in the experiment, and the uptake of magnesium.

Basically it consisted of four 6×6 Latin squares, A, B, C and D. On six untreated shoots, leaves from positions 3 to 8 inclusive were taken for A, and from positions 9 to 14 inclusive for B ; on another six shoots positions 3 to 8 were used for C, and positions 9 to 14 for D. Thus A acted as a control for C, and B as a control for D. A set of leaves was removed from each group at the following times : at 11·05, 11·25, 13·45, and 16·20 hours on the first day, and at 09·20 hours on the second and third days. Shoots providing groups C and D were dipped with 2% magnesium

sulphate solution immediately after picking the first sets of leaves. In this experiment the leaves, collected over a period of days, were dried in batches. The dry weight of one batch was found to be significantly different from that of the rest, probably because of inadequate drying of that particular batch ; the dry weights of the leaves have therefore not been used in this experiment. The results (Fig. 5), which are expressed in terms of magnesium per leaf, were statistically treated by analysing control and treated groups together (i.e. A and C, or B and D), and examining the interaction between " occasion 1 *v.* occasions 2–6 " and " treatment *v.* control ". For leaf positions 3–8 (groups A and C), this interaction was significant ($P<0\cdot05$), but for 9–14 (groups B and D) it was not. Thus the magnesium content

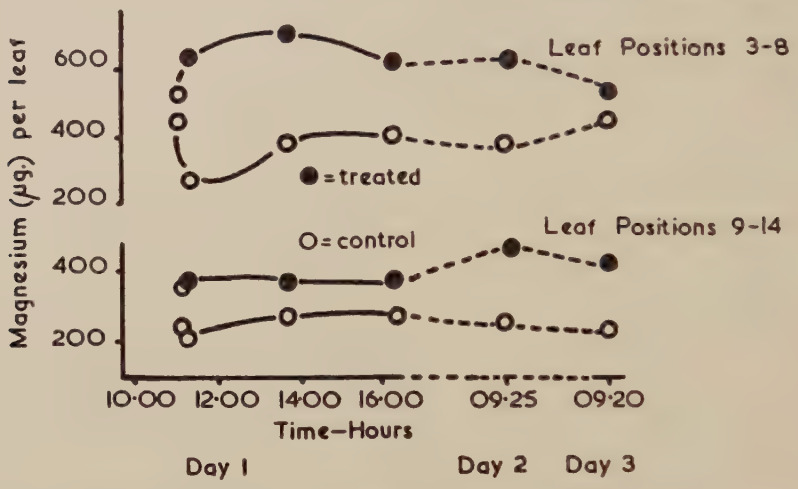

Fig. 5.

Changes in magnesium content of control leaves, and of leaves treated with 2% magnesium sulphate solution immediately after picking the first set of leaves ; leaves from two different sets of leaf positions.

of leaves in positions 3–8 was increased by dipping, as compared with that of untreated controls, and it is apparent from Fig. 5 that this increase occurred in the first fifteen minutes after dipping. No increase was shown in the magnesium content of leaves in positions 9–14 over this period. There is evidence from the work of Oland and Opland (*loc. cit.*) that older leaves can sometimes take up magnesium during the night and so it was desirable to examine the present data for leaves in positions 9–14 to see if this had occurred. The interaction between " occasions 1–4 v. occasions 5–6 " and " treatment v. control " was examined and found to be significant ($P<0\cdot001$) ; i.e. the magnesium content of treated leaves had increased significantly overnight compared with that of the controls. Thus the magnesium content of leaves in positions 9–14 did not increase until more than 5 hours had elapsed after dipping, whereas that of leaves in positions 3–8 increased within 15 minutes.

It will be apparent from Fig. 5 that the magnesium content of untreated leaves varied appreciably during the course of the experiment and that, as expected from the results of earlier experiments, this variation was less in the lower leaves ; in neither, however, was the difference significant. From the statistical analysis it was

also shown that the residual variation for leaves 3–8 was significantly greater than for leaves 9–14 ($P<0{\cdot}002$) ; it is clear, therefore, that more precise experiments result from the use of more mature leaves, i.e. leaves lower down the stem. Such experiments, however, are no substitute for experiments on younger leaves, for, as shown, these behave differently in that they take up magnesium more readily. To use foliar sprays more efficiently in the field, it is obviously necessary to know the conditions under which older leaves as well as younger will take up magnesium readily ; it is convenient that the use of older leaves is likely to result in more precise determinations.

DISCUSSION.

In the cotton plant there is a diurnal variation in the magnesium content of the leaves due to magnesium moving into or out of those leaves from or to the rest of the plant (Phillis and Mason, *loc. cit.*). The above experiments show that in M.III apple rootstocks a similar event may occur but over a shorter time interval ; in the course of an afternoon, magnesium can enter shoots from, and then return to, other parts of the plant. There is no evidence of its re-distribution within that part of the shoot considered in these experiments. The variation in magnesium content of leaves nearer the tip is greater than that of leaves lower down the stem, and a similar behaviour occurs in the stem itself. These facts suggest that magnesium moving into the shoots is supplied preferentially to younger leaves. Consequently, in experiments in which the uptake of magnesium from foliar applications is to be measured, changes in the natural magnesium content can be minimized by working with leaves lower down the shoots. It has also been shown that the residual variation in experiments using such material is lower and the experiments are therefore more accurate.

It must be emphasized that the quoted changes in magnesium content of untreated leaves have been obtained with leaves of M.III rootstock ; in other work (Allen, 1960b) it was shown that, for a given leaf position, these changes are smaller for leaves of Worcester Pearmain apple on M.II rootstock.

It has been shown that there is a difference in behaviour between younger and older leaves in that the former take up magnesium more readily, a result which is in agreement with the findings of Oland and Opland (*loc. cit.*). Moreover, on comparing Figs. 4 and 5, it will be seen that, when leaves 3–8 were dipped with 2% magnesium sulphate solution on different occasions, magnesium could be taken up within 15 minutes (Fig. 5), or not taken up at all over a period of two days (Fig. 4). The effect of a single application of 2% magnesium sulphate solution to field material can thus lead to very different results on different occasions. Further work designed to explain this variation in behaviour is projected.

ACKNOWLEDGMENTS.

The writer is greatly indebted to Dr. G. H. Freeman for many helpful discussions on the statistical side of the work.

SUMMARY.

1. In M.III rootstocks, grown as a hedge, significant changes in the magnesium content of untreated leaves occurred during the course of a day.

2. These changes were greater in younger than in older leaves, but there was no evidence that magnesium was moving from one leaf to another, or to the woody part of the stem ; it would therefore seem that the movement of magnesium was into or out of the entire shoot.

3. In determinations of magnesium uptake from foliar applications of magnesium sulphate, the natural fluctuation in magnesium content was minimized, and the residual variation in an experiment significantly reduced, by working with older rather than younger leaves. The effect of this natural variation was allowed for by the use of suitable controls.

4. The younger leaves of shoots dipped in a 2% solution of hydrated magnesium sulphate took up magnesium more rapidly than the older ones.

5. The time elapsing between dipping and a subsequent increase in magnesium content varied markedly between different experiments ; thus in one experiment treatment failed to produce a change in the magnesium content of leaves over a period of two days, in another a significant increase occurred within 15 minutes.

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THE UPTAKE OF METALLIC IONS BY LEAVES OF APPLE TREES

II. THE INFLUENCE OF CERTAIN ANIONS ON UPTAKE FROM MAGNESIUM SALTS

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Two groups of workers studying the uptake of magnesium from foliar sprays have reported that magnesium can enter apple leaves less readily from solutions of the sulphate than from its other salts. Thus Fisher and Walker (1955) showed that magnesium was taken up most readily from nitrate and chloride solutions, least readily from sulphate and phosphate and at an intermediate rate from acetate. Oland and Opland (1956) found that magnesium entered the leaf more rapidly from acetate than from sulphate but that the acetate caused damage to the leaves. The present work, salient conclusions from which have been previously published (Allen, 1959), has aimed at an understanding of the processes involved in the uptake of this metal from such salts, and thereby at an explanation of their differing behaviours. Results obtained from the use of solutions of the sulphate, chloride and nitrate follow.

Material and methods.

A closely planted row of four-year-old Worcester Pearmain apple trees on M.II rootstock, pruned heavily each year to provide large numbers of new shoots, was used as a source of material. All of the experiments but one were performed on the trees in the field.

The techniques previously described (Allen, 1960) were upon occasions modified as follows : when it was required to know the amount of magnesium remaining on the outside of the leaf, the latter was detached, washed in a known amount (about 20 ml.) of water, and the concentration of magnesium in this washing determined. The leaf was washed once more and then put on a wire to await drying and subsequent weighing, ashing, and analysis.

In each field experiment six trees were used and a shoot from each tree was allocated to each solution to be employed in the experiment and to a control group. Leaves 7 to 12 inclusive, counting down the shoot from the first fully expanded leaf, were used throughout to minimize changes in the natural magnesium content of leaves (Allen, 1960), and on each occasion that leaves were to be picked one leaf was taken from each shoot within a group according to a 6×6 Latin square design. In all experiments changes in the controls were so small compared with the change in magnesium content brought about by treatments that their effect has been ignored.

Where detached leaves were used, thirteen shoots, each carrying sufficient leaves, were brought into the laboratory and labelled above the 4th and below the 12th leaf positions ; 13 sets of 9 leaves, selected according to a 13×9 Youden square design, were picked from between the labels on the shoots, the nine leaves in a set being held in order by the petiole in the jaws of plastic pegs mounted on a piece of wood. A set of leaves was treated by immersing it in the appropriate magnesium salt solution

(containing as usual 0·02% Triton X-100 as wetting agent) for the desired length of time ; it was then removed, washed in running water, and the leaves transferred serially to a wire to be dried. Thereafter the leaves were treated in the same way as already described. In this particular experiment one set of leaves was used as untreated controls, four sets were immersed in M/10 magnesium sulphate solution, four in M/10 magnesium nitrate and four in M/10 magnesium chloride, and one set was removed from each solution at 5, 10, 20 and 40 min. intervals after first immersing the leaves.

Results.

First experiment.

This was designed to compare the uptake of magnesium from the following solutions ; 2% $MgSO_47H_2O$, 2% $Mg(NO_3)_26H_2O$, and 2% $MgCl_26H_2O$. Four groups of six shoots were used, and sets of leaves were removed at the following times : at 14·30, 14·45 and 16·25 hours on the first day, at 09·20 hours on the second day, and at 09·20 and 16·30 hours on the third day.

The results are shown in Fig. 1. Within a given group the variance of the magnesium per unit dry weight of treated leaves was greater than that of untreated

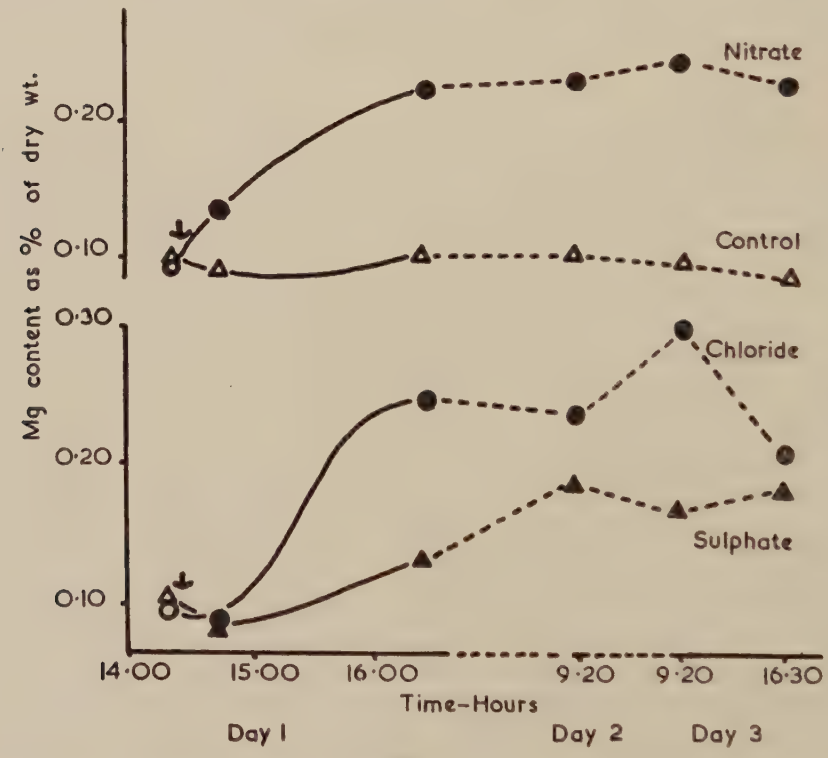

Fig. 1.

Changes in the magnesium content of control leaves, and of leaves treated with 2% solutions of various magnesium salts. Leaves were treated at the time indicated by the arrows.

leaves, and the logarithm of the magnesium per unit dry weight for individual leaves has therefore been used in the statistical analysis ; the results illustrated in Fig. 1 thus represent geometric means of magnesium per unit dry weight of leaf. Magnesium was taken up from both chloride and nitrate solutions on the same day as the leaves were treated and by 16·25 hours an amount had been taken up which was not further significantly increased at the end of the experiment. The fifth point for the chloride was just significantly higher than the sixth ($P<0·05$), but not higher than points three or four at this level of significance ; for nitrate none of these points was significantly different from the others. The magnesium content of sulphate-treated leaves was not different at 16·25 hours from that of the untreated, but overnight a significant increase occurred. At the end of the experiment the magnesium content of treated leaves was higher than that of untreated ($P<0·001$ for each salt) and there was no real difference between the increases brought about by the three solutions ($P>0·2$). Thus, with 2% chloride or nitrate, magnesium was taken up by the leaf within two hours of dipping, after which there was no further uptake ; with the sulphate solution there was no significant uptake within the first two hours but overnight the level of magnesium content was not significantly different from that given by chloride or nitrate.

It is, of course, true that 2% solutions of magnesium chloride, nitrate and sulphate contain different amounts of magnesium, the solutions being respectively 0·98, 0·78, and 0·81 decimolar, but since the chloride solution contained more magnesium than the sulphate, and the nitrate solution slightly less, it is evident that it is not changes in the amount of magnesium in solution which was causing this marked difference in behaviour between the three salts. Nevertheless, subsequent experiments were carried out with M/10 solutions, so that the amount of magnesium applied was the same for all three salts.

Second experiment.

In addition to M/10 solutions of magnesium chloride, nitrate and sulphate the first named was also used at M/5 and M/20. The first set of leaves was removed from each group of six shoots, which were then dipped at 11·30 hours. Five minutes later, when drainage of excess solution from the surface of the leaves had ceased, one set was picked from each of the five treated groups and arranged on wires in such a way that the leaves were not in contact with each other. When the surface deposit on these unwashed leaves had dried, they were brought into the laboratory and their magnesium contents determined. Further sets of leaves were removed at 13·20, 15·00, and 16·20 hours, and finally at 09·20 hours the following morning. The amount of magnesium present on the surface of treated leaves and the content of washed leaves were determined as already described. It was thus possible to specify the amount of magnesium recovered from within the leaf and also the surface magnesium plus that within the leaf. It was convenient to treat the data in this way so that the results for total recovery from leaves picked after five minutes could be directly compared with those from leaves picked subsequently. Separate analyses of variance were carried out on the logarithm of the leaf magnesium per unit dry weight, and on the logarithm of the total recovery of magnesium per unit dry weight. The appropriate mean values for the various treatments, expressed as percentages, are shown in Table I.

Table I.

Amounts of magnesium recovered from leaves at various times after treatment with solutions of magnesium salts, together with the relative humidities at those times.

Solution used for dipping		Magnesium recovery (% of dry wt. of leaf)					
		Immediately before dipping	After dipping				
			5 min.	2 hr.	3½ hr.	5 hr.	22 hr.
$\frac{M}{10}$ $MgSO_4$	Total	—	0·33	0·36	0·35	0·29	0·20
	Within leaf	0·08	—	0·15	0·16	0·12	0·20
$\frac{M}{10}$ $Mg(NO_3)_2$	Total	—	0·30	0·34	0·33	0·32	0·23
	Within leaf	0·08	—	0·24	0·22	0·23	0·23
$\frac{M}{10}$ $MgCl_2$	Total	—	0·32	0·34	0·32	0·31	0·26
	Within leaf	0·09	—	0·24	0·20	0·21	0·25
$\frac{M}{5}$ $MgCl_2$	Total	—	0·49	0·42	0·49	0·51	0·43
	Within leaf	0·07	—	0·26	0·30	0·37	0·39
$\frac{M}{20}$ $MgCl_2$	Total	—	0·25	0·24	0·22	0·25	0·20
	Within leaf	0·09	—	0·18	0·16	0·19	0·19
Untreated control	Within leaf	0·07	—	0·08	0·09	0·08	0·09
Relative humidity %		72		55	52	56	96

Sulphate v. *nitrate* v. *chloride*. M/10 solutions of magnesium nitrate and chloride behaved in a remarkably similar manner : for each, the magnesium content of the leaf increased significantly ($P<0·001$) within two hours of dipping and did not change thereafter, even though there was still an appreciable quantity of magnesium left on the outside of the leaf. The total recovery of magnesium did not vary significantly over the period from 5 minutes to 5 hours after dipping, showing that there was no real loss of magnesium from the treated leaves to the rest of the tree during this time ; the total recovery did fall significantly overnight ($P<0·05$), but this loss could be attributed to light rain which fell shortly before the last batch of leaves was picked.

There was a significant increase within two hours in the magnesium content of leaves treated with magnesium sulphate solution and, by the end of the experiment, this had increased still further ($P<0·05$). The magnesium content of the leaves five hours after dipping was lower ($P<0·05$) than at two hours, but this cannot at present be accounted for. As with the other salts, the total recovery figures did not vary significantly on the day on which the leaves were dipped, but did fall ($P<0·05$) overnight.

Thus uptake was more rapid from chloride and nitrate than from sulphate. By subtracting the magnesium content per unit dry weight of the control leaves from the corresponding values for the best estimate of total recovery, and from the leaf content at the end of the experiment, estimates can be made of the amount applied to the leaf and of the increase in leaf magnesium content brought about by a given treat-

ment, respectively. These values have been plotted in Figs. 2 and 3, together with data from the rest of the experiment. From these figures it can be said that, with the chloride- and nitrate-treated leaves, about two-thirds of the magnesium retained on the surface entered the leaf within two hours, and that practically all that was left on the outside at this time was lost from the system by the following morning, possibly by being washed off by rain. The same amount was retained on the surface of sulphate-treated leaves, but two hours after dipping only one-third of this had entered the leaf; by the following morning about half had entered, the rest having been lost from the system. The overall increase in magnesium content of the sulphate-treated leaves, though slightly lower than that of leaves treated with chloride or nitrate, was not significantly so ($P>0\cdot2$).

Varying the concentration of magnesium chloride solution. The results for the M/10 and the M/20 solutions were similar: about two-thirds of the magnesium initially retained was taken up by the leaf within two hours and there was no further significant change; the bulk of the magnesium left on the outside of the leaf was lost from the system overnight. The results obtained with the M/5 solution differ in the following two respects:

(*i*) The magnesium content of the leaf did not reach its final value within the first two hours; at this time about half the magnesium retained at dipping had gone into the leaf and three hours later a further increase ($P<0\cdot05$) had occurred. The final increase was not significantly different from this and represented about two-thirds of the magnesium retained by the leaf.

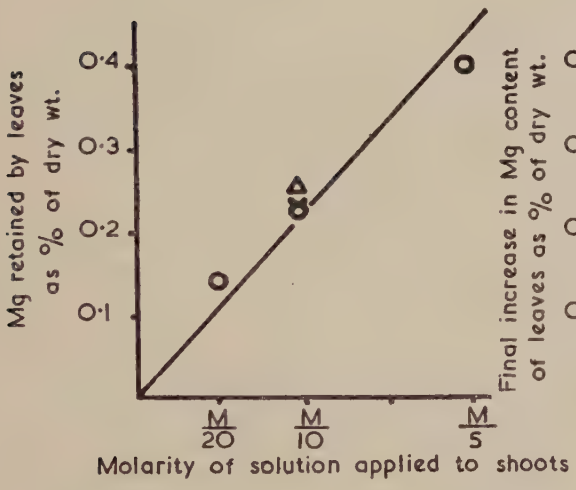

Fig. 2.

The amount of magnesium retained by leaves when treated with various magnesium salt solutions.

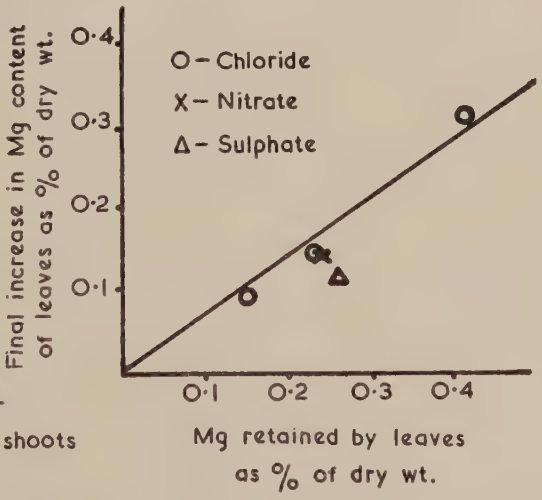

Fig. 3.

Relationship between the final increase in the magnesium content of leaves caused by various magnesium treatments and the amount of magnesium retained by the leaves from those treatments.

(*ii*) There was no significant difference in the total recovery figures throughout the experiment. However, it will be apparent from Table I that only little magnesium could be washed from the outside of the leaves at the end of the experiment, so that, even though the losses from the system were not significant, it is clear that the M/5 solution was behaving similarly to the M/10 and M/20 solutions in that most of the surface magnesium was lost overnight.

Fig. 2 shows that a straight line adequately represents the relationship between concentration and the amount of magnesium retained by the leaves. Fig. 3 shows the relationship between the final increase in magnesium content and the amount retained by the leaves and it will be seen that for the chloride solutions a straight line passing through the origin is a good representation of the facts ; i.e. the same proportion of retained magnesium goes into the leaf for all three solutions. It will also be seen that the point for the nitrate solution is almost on the line, whereas the sulphate point is well off it. However, as already mentioned, the final amounts of magnesium taken up from M/10 solutions of sulphate, nitrate, or chloride do not differ significantly.

Third experiment.

This was designed to determine whether there is any inherent difference in the rates at which magnesium is taken up from solutions of the three salts. Detached leaves were immersed, as already described, for periods of 5, 10, 20 and 40 min. in M/10 solutions of magnesium sulphate, nitrate and chloride ; the dry weights and magnesium contents of the washed leaves and of a set of untreated leaves were measured. Results, expressed in terms of % magnesium per dry weight of leaf, are shown in Fig. 4. A statistical analysis of the logarithms of magnesium content per unit of dry weight of individual leaves showed no difference in the amount or rate of uptake between the three solutions. It is proposed to leave discussion of the shape of the uptake curve for the present ; whatever the shape of the curve, it is clear that uptake from each of the three solutions follows the same pattern and that magnesium enters the leaf at the same rate from each.

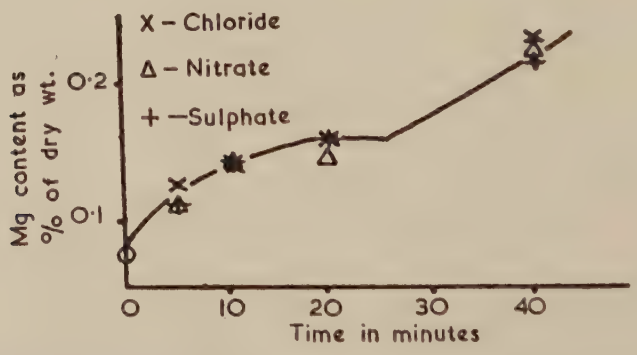

FIG. 4.

Magnesium content of leaves immersed for various times in M/10 solutions of magnesium salts.

DISCUSSION.

The rates at which magnesium is taken up when leaves are dipped in solutions of magnesium chloride, nitrate or sulphate are compared in two of the experiments described in this paper ; other experiments, not described here, were in agreement with the results of these and with the findings of Fisher and Walker (1955), namely, that magnesium is taken up more rapidly from the chloride and nitrate than from the sulphate. Application of the chloride usually brought about a significant effect on the day of application or, at the latest, by the following morning. Uptake from the sulphate on the day of application occurred relatively infrequently but, in just over half of all the experiments, a significant effect had been brought about by the morning following treatment ; according to Allen (1960) there may be no significant uptake over a period of days.

When leaves were immersed in equimolar solutions of magnesium chloride, sulphate and nitrate, magnesium was taken up equally rapidly from each ; yet, when they were momentarily dipped in the same solutions, the rate of uptake was different for different salts, though the same amount of magnesium was initially retained on the leaf surfaces from all three. It would be expected that, as long as the dipped leaves were wet and subject to conditions similar to those which obtained when they were immersed, magnesium would be taken up equally readily from the three solutions. However, evaporation occurs and sometimes proceeds until the magnesium salt crystallizes out, at which point a difference would arise between the salts which might account for the observed differences in behaviour. At 20°C. the relative humidity of air in equilibrium with saturated solutions of magnesium sulphate, acetate, nitrate, and chloride is 82, 65, 55 and 33% respectively. If the relative humidity of the air were greater than that of air in equilibrium with a saturated solution, the latter (or even the crystals from which it is derived) would take up water vapour from the air ; if it were less, the solute would eventually crystallize out. Thus, at 20°C., a relative humidity of 32% would cause solutions of all four salts to crystallize out, and a relative humidity of 60% would cause the sulphate and acetate to crystallize out, but would allow the chloride and nitrate to remain in solution at a concentration determined entirely by the relative humidity and temperature.

A consideration of the measured relative humidities quoted in Table I leads to the conclusion that chloride would have remained in solution on the leaf surface throughout that experiment, and that nitrate would have lost water after the first two hours but regained it a few hours afterwards. The sulphate solution, on the other hand, would have dried out at once, and only been brought into solution overnight. It is thought that a magnesium salt in the form of dry crystals on the leaf surface is inaccessible to the plant ; thus the magnesium content of sulphate-treated leaves could only be increased in the short period between dipping the leaves and the surface film of liquid drying out, and then again at some time during the night. There would be no such inhibition of entry in chloride-treated leaves and it is clear from Table I that, for the M/10 solution, uptake of magnesium was complete within two hours. It is also clear that uptake of nitrate was complete in these two hours and that drying out after that time came too late to affect the course of the experiment. Thus, assuming that magnesium can only enter the leaf from a liquid on the leaf surface, differences in behaviour between the three salts can be accounted for on a basis of the different conditions under which their solutions dry out.

Conditions in the experiment of Table I were never such that chloride solutions

on the leaf surface would dry out ; thus, regardless of the applied concentration, evaporation would proceed until the vapour pressure of the resulting solution was equal to that of the surrounding air. In other words, M/20, M/10 and M/5 magnesium chloride solutions, placed on the leaf surfaces, would all evaporate until they reached the same concentration, though, of course, the volume of this final solution would depend on the initial concentration applied. Eventually there would be three different volumes, all at the same concentration, instead of three equal volumes at different concentrations, as applied ; and since the rate at which magnesium is taken up is determined by the concentration in solution, it is obvious that the greater amount of magnesium in a larger volume of solution would take longer to enter than the smaller amount in a smaller volume, both solutions being at the same concentration. This is in accord with the finding that magnesium uptake from the M/5 solution continued after uptake from the two weaker solutions had ceased.

When uptake ceased, at least a third of the magnesium initially retained was still present on the surface of chloride-treated leaves, under atmospheric conditions which would not allow of drying out. It seems, therefore, that the process of uptake came to a halt while there was still magnesium in solution on the leaf surface. The same proportion of the magnesium initially present on the leaf surface was taken up from the three chloride solutions, but the amount taken up and retained within the leaf varied markedly. It is difficult to reconcile this fact with the suggestion, made above, that deposits from the three solutions are finally present on the leaf surface as different volumes of solution but all at the same concentration. A possible explanation involves the assumption that not all of the leaf surface is able to take up magnesium. If, for example, it was only able to penetrate the *lower* surface, then only that part of the applied solution retained on that surface could enter the leaf, and this would represent a fixed proportion of the applied magnesium, and be independent of the concentration of magnesium chloride solution. The distinction upper *v.* lower surface is used for illustration, but the proposed explanation would apply to any division of absorbing *v.* non-absorbing leaf surface. Obviously much more detailed work will be required to solve this aspect of magnesium absorption by leaves.

The explanation put forward for the differences in behaviour between the three salts is tentative ; if correct it would mean that, apart from the age of the leaf, which has been shown by Oland and Opland (1956) and Allen (1960) to affect the uptake of magnesium, the behaviour of a leaf dipped in a solution of a magnesium salt would depend on (*a*) the salt being used, and (*b*) the atmospheric conditions during and after treating the leaves. Those salts that are likely to remain in solution over a wide range of atmospheric conditions, namely the chloride and the nitrate, would have a considerable advantage over salts such as the sulphate as far as entry into the leaf is concerned, and this advantage might be even more pronounced in arid climates. Under English weather conditions it is likely that deposits of the sulphate would eventually be dissolved by a high atmospheric humidity ; unfortunately it is also possible that the salt might be washed off by rain before an appreciable amount of magnesium could enter the leaf. The use of the chloride should reduce the probability of such a misfortune. Therefore, provided that it can be shown to be safe, magnesium chloride might with advantage replace sulphate in foliar sprays applied to correct deficiency. Experiments to compare the efficacy of these salts in reducing the effects of deficiency are in progress, as are others in which uptake of magnesium from various salts is measured on trees in the field under different conditions of humidity.

SUMMARY.

1. When shoots of Worcester Pearmain apple on M.II rootstock, still attached to the tree, were momentarily dipped in a solution of the appropriate salt, magnesium was taken up by leaves more rapidly and dependably from the chloride or nitrate than from the sulphate.

2. The amount of magnesium initially retained on the surface of leaves dipped in a M/10 solution of one of the three salts was independent of the salt used ; for the chloride and nitrate, uptake was complete within two hours of dipping ; some magnesium was taken up from the sulphate during this period, but then uptake ceased and was resumed at some time between 5 hours after dipping and the following morning, at which time the amount taken up did not vary between the three salts.

3. Uptake following dipping continued longer from M/5 than from M/10 or M/20 solutions of magnesium chloride, but for all three solutions the final increase in leaf magnesium content represented two-thirds of that initially retained on the leaf surface.

4. The rate at which magnesium entered leaves which were immersed in a M/10 solution of one of the three salts was shown to be independent of the salt used ; differences in rate of uptake in momentarily dipped shoots were therefore attributed to differences in behaviour of surface films of the three salts left after dipping.

5. From a consideration of the vapour pressure of water in equilibrium with saturated solution of the three salts and the relative humidities during an experiment it was shown that the chloride and nitrate must have been in solution, and the sulphate, in the form of a dry deposit, on the leaf surface shortly after dipping the shoots ; observed differences in the times at which uptake occurred were related to these differences in the states of the deposits.

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THE EFFECT OF SOIL pH AND MANGANESE TOXICITY UPON THE GROWTH AND MINERAL COMPOSITION OF THE HOP PLANT*

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THE hop plant is normally grown under clean cultivation with heavy dressings of fertilizers. Under these conditions the continual working and leaching of the soil, particularly on the lighter soil types, can result in the development of marked acidity which may influence the growth of the plant.

Little information has been published on the effect of soil acidity on hop growth. Hall (1903), Burgess (1936, 1950), and McCollam (1939), all state that the hop grows best on a neutral soil, but Doerell (1933) pointed out that hops could be grown successfully over a wide range of soil pH conditions. Preliminary observations made by Thompson *et al.* (1950), on hop plants growing in light soil with a pH of approximately 4·6, suggested that certain leaf symptoms were associated with a high manganese content in the leaf. When the manganese content was higher than 1,000 p.p.m. iron deficiency was induced. From a field experiment carried out on this soil (Thompson *et al.*, 1952) it was concluded that only young plants were sensitive to soil acidity and that fully established hops could make good growth at much lower pH levels than had previously been thought to be the case. Since potassium deficiency is a common problem in hop culture (Thompson, 1952) and uptake of potassium might be expected to be favoured by low soil pH and calcium levels, it was decided to examine experimentally the nutrient uptake of the hop under acid soil conditions. Investigations were accordingly carried out at Wye College, Kent, during 1951–54 as part of the programme of the Department of Hop Research.

During 1951–53 two experiments were carried out. One of those was a three years' study of the growth and mineral composition of hop plants grown in pots of soil ; the other, carried out in 1953 only and in sand culture, was a study in detail of points arising from the results of the soil culture experiment. Much information was obtained but only the more important data are discussed in this paper ; the original text (Watson, 1955) should be referred to for full details and associated statistical data.

SOIL-CULTURE EXPERIMENT.

This was planned to study the effect of soil type, soil pH and nutritional status upon the mineral composition of the hop. Treatments were :

Three soil types—

S_1—a clay ; Shaw series alluvium over Wadhurst clay.

S_2—a loam ; Langley series brickearth derived from Greensand over Hythe Beds.

S_3—a very fine sandy loam ; Pembury series on Tunbridge Wells Sand.

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Four soil pH levels—

4·5, 5·5, 6·5 and 7·5.

Two nutritional levels—

deficient and normal NPK levels with respect to commercial field conditions. For this purpose available P and K were estimated by quick-test soil analysis methods using Morgan's reagent (1937) as extractant.

Treatments were applied in duplicate giving a total of 48 plants.

The experimental plants, clonal Fuggle N hops, were established from basal cuttings in the spring of 1951, in large half-barrels containing approximately 170 pounds of soil. The plants were grown in the open and were watered when necessary with rain water stored for the purpose. Bine growth was trained up strings supported on wirework 12 feet (3·6 metres) high.

The experimental pH and nutritional levels were maintained as closely as possible by suitable lime and fertilizer additions, calculated from lime-titration curves and quick-test analyses of the soil respectively.

Results.

Visual recordings.

S_1. This soil produced strong, vigorous plants each year. No leaf symptoms of nutritional disorders, apart from a slight nitrogen deficiency in plants at low nutrition during 1953, were observed. Plants growing at pH 4·5 under low nutrition showed somewhat weaker growth than was seen in the other treatments ; otherwise there was no appreciable difference between plants at the two nutritional levels.

S_2. Strong plants were produced each year but considerable differences in vigour existed between plants growing under low and normal nutritional conditions. Severe manganese toxicity was evident at pH 4·5, particularly with low nutrition. Affected plants showed heavy black speckling on the undersides of leaf ribs and petioles, particularly on the older leaves and along the veins. Young leaves were harsh to the touch, pale green in colour, and showed interveinal transparent areas which developed into necrotic patches. Plants growing at pH 4·5, but at the normal nutritional level, showed some manganese toxicity symptoms but grew satisfactorily and showed normal cone development. The only deficiency symptoms observed were those of nitrogen deficiency in plants growing under low nutrition.

S_3. In 1951 this soil produced stunted plants, but in 1952 and 1953 the plants were similar to those grown on soil S_2. There was much more vigorous growth at the normal than at the low nutrition level. Manganese toxicity was present but to a lesser extent than in the plants growing on soil S_2. As with soil S_2, there was less evidence of manganese toxicity at normal than at low nutrition.

Crop yield.

The yield of dried cones from each treatment was recorded. Owing to the artificial nature of the conditions under which the plants were grown, precise comparisons of treatments on a yield basis have not been attempted in this paper. The following observations, however, have been noted.

With the clay (S_1) little difference in yield was seen between plants at the two nutritional levels. With soils S_2 and S_3, plants at low nutrition appeared to yield less than did those at normal nutrition, this depression in yield being most apparent at pH 4·5.

Leaf analysis.

Leaf sampling was carried out on several occasions in each season, but only the mean data for samples of " first fully-formed leaves " (Watson, 1952) taken in July 1953 are presented in this paper (Tables I and II). The discussion of the leaf analysis data is primarily based on these results, but certain general conclusions have been drawn from a consideration of all the data obtained.

Nitrogen. With the clay soil S_1, there was no variation of nitrogen content with soil pH, but leaves of plants at normal nutritional level contained rather higher levels of nitrogen than did those at low nutritional level. With soils S_2 and S_3, there was no

TABLE I.

Soil-culture experiment. Leaf contents of Ca, Mg, K (as % oven-dry weight).

Soil	Soil pH	Low nutrition			Normal nutrition		
		Ca	Mg	K	Ca	Mg	K
S_1	4·5	0·89	0·29	2·39	0·81	0·25	2·98
	5·5	0·96	0·33	2·43	0·93	0·32	2·75
	6·5	0·88	0·29	2·43	0·88	0·29	2·82
	7·5	0·93	0·29	2·29	0·90	0·27	2·64
S_2	4·5	0·94	0·48	3·30	0·81	0·40	2·98
	5·5	0·99	0·37	2·15	0·97	0·38	2·67
	6·5	1·12	0·29	2·06	1·02	0·38	2·65
	7·5	1·33	0·34	2·08	1·31	0·37	2·73
S_3	4·5	0·86	0·45	2·64	0·60	0·37	2·90
	5·5	1·07	0·38	1·98	0·97	0·39	2·76
	6·5	1·30	0·38	2·09	0·87	0·35	2·62
	7·5	1·05	0·33	2·04	1·10	0·38	2·38

TABLE II.

Soil-culture experiment. Leaf contents of N, P and Mn; N and P as % Mn as p.p.m., of oven-dry weight.

Soil	Soil pH	Low nutrition			Normal nutrition		
		N	P	Mn	N	P	Mn
S_1	4·5	3·39	0·34	373	3·78	0·33	357
	5·5	3·51	0·35	73	3·73	0·38	78
	6·5	3·55	0·40	54	3·66	0·34	56
	7·5	3·60	0·37	37	2·75	0·40	36
S_2	4·5	5·91	0·67	1,796	4·03	0·39	903
	5·5	3·42	0·43	193	3·92	0·42	280
	6·5	3·59	0·43	81	3·94	0·43	254
	7·5	3·87	0·44	85	4·03	0·42	233
S_3	4·5	5·10	0·49	998	3·91	0·40	478
	5·5	3·62	0·39	142	3·89	0·43	107
	6·5	3·83	0·47	78	3·79	0·41	75
	7·5	2·31	0·47	59	3·94	0·38	88

variation in nitrogen content over pH values of 5·5, 6·5 and 7·5 and, at these pH values, plants contained more nitrogen at normal than at low nutritional level. However, the percentage leaf nitrogen content of plants growing at pH 4·5 and under low nutrition conditions was markedly higher than that of plants growing at higher pH values, and was also higher than that of plants growing at the same pH but with normal nutrition.

Phosphorus. Little variation in leaf phosphorus content due to soil pH or nutritional level was found, but high levels of leaf phosphorus were recorded in plants growing in soils S_2 and S_3 at pH 4·5 with low nutrition.

Potassium. In general, with all soils, leaf potassium content increased with decrease in soil pH and was higher under normal than under low nutritional conditions. The only exception to this was with soil S_2, where potassium content at soil pH 4·5 was higher at low than at normal nutrition. This effect paralleled the increases in leaf nitrogen and phosphorus contents noted above.

Calcium and magnesium. Leaf contents of calcium, magnesium, and potassium were found to interact markedly. With all soils, but particularly with S_2 and S_3, increase in soil pH caused an increase in leaf calcium content accompanied by a decrease in potassium. Magnesium content was little affected by soil pH.

Manganese. In general, with all samplings, leaf manganese contents were in the order $S_2 > S_3 > S_1$. Nutritional treatment had little consistent effect on manganese content, but in the third year of growth all plants under low nutrition conditions and at soil pH 4·5 contained considerably higher amounts of manganese than did plants with normal nutrition at that pH level. With all soils leaf manganese content increased with decrease in soil pH, with a sharp increase taking place as the value fell from 5·5 to 4·5.

Iron and aluminium. No consistent effects were noted.

SAND-CULTURE EXPERIMENT.

By 1953 it was apparent that the main treatment effect showing in the soil-culture experiment was that due to acidity at pH 4·5 and that this effect was associated with manganese toxicity. Only limited information was, however, available concerning the possible effect of aluminium at this low pH. A sand-culture experiment was therefore laid down to study in detail the effects both of manganese toxicity on the mineral composition of the hop and of high levels of aluminium when applied in culture solution.

Treatments were :

Three calcium levels—low, medium and high.

Two nutritional (N, P, K and Mg) levels—low and high.

Two levels each of aluminium and manganese—normal trace element levels, and potentially toxic levels.

The 24 treatments were applied in duplicate.

The composition of the solutions used for these treatments is given in Table III. The high aluminium and low phosphate solutions had an initial pH value, at application, of 3·6 and, to ensure that all culture solutions had a similar initial pH, combinations of different phosphate salts were used and where necessary sulphuric acid was added. A very high concentration (5·6 m.e./litre) of manganese in the high manganese solution was at first thought to be necessary, as only a limited growing period

was available in which to induce toxicity symptoms. After the development of severe manganese toxicity reported below, the level of applied manganese was lowered to 3·4 m.e./litre.

Rooted soft-wood cuttings of Petham Golding hops were planted in large (12 in.) bituminized clay pots filled with Leighton Buzzard sand and the plants were fed with a normal nutrient solution for one month before treatments began.

Table III.

Composition of nutrient culture solutions.

Treatment	m.e./litre						
	Ca	Mg	K	N	P	Al	Mn
Low calcium	2·5						
Medium calcium	7·5						
High calcium	22·5						
Low nutrition		1·7	2·6	7	2		
High nutrition		5·0	7·7	21	6		
Normal aluminium						0·03	
High aluminium						4·00	
Normal manganese							0·01
High manganese							5·60

All treatments received trace additions of Fe, Cu, Zn, B and Mo.

Visual recordings of the plants were carried out and five weeks after treatment leaf samples were taken by selecting the first fully-formed leaf plus leaves from four to five nodes below this point. The more important of the analytical results obtained from this sampling, given in Tables IV and V, are discussed below.

Results.

Visual recordings.

Low aluminium, low manganese treatments. Plants of this group grew satisfactorily. High nutrition plants produced leaves of normal size while those at low nutrition produced small or very small leaves. Bine growth continued in all plants throughout the experimental period.

Low aluminium, high manganese treatments. Manganese toxicity symptoms were apparent in all plants in this group, particularly in those receiving combined low calcium and low nutrition. Leaves on the latter showed an extreme form of toxicity symptom, characterized by large black-brown necrotic patches on and below the surface of bines and petioles ; cessation of growth, followed by death of the growing points, occurred within a fortnight of commencement of the treatments. Plants with high nutrition did not show death of the growing point and limited growth occurred after the applied manganese level had been reduced to 3·4 m.e./litre. A general feature throughout this group was the development of a light yellow chlorosis

of the upper leaves. Some of these when painted with ferrous sulphate solution eventually turned green, suggesting that the chlorosis was due to iron deficiency.

High aluminium, low manganese treatments. Plants in this group were typically small, with small leaves of a pale green colour. They showed no leaf scorch and resembled normal plants in miniature. In the high nutrition treatment the leaf colour was darker and limited bine growth occurred.

High aluminium, high manganese treatments. These plants showed considerably modified manganese toxicity symptoms. All of them displayed the black speckling and veinal necrosis typical of manganese toxicity, but the leaves did not become distorted or harsh to the touch. In particular, it seemed that the severity of manganese toxicity symptoms shown here was appreciably less than in the plants receiving combined low calcium, low nutrition, low aluminium, high manganese treatment. High calcium high nutrition plants of the group were recorded at the end of the season as being surprisingly vigorous, despite the presence of manganese toxicity symptoms on their lower leaves. As with the low aluminium high manganese plants, chlorosis of the upper leaves was characteristic of this group.

Leaf analysis.

Nitrogen (Table V). Leaf nitrogen content was increased by high nutrition treatment and decreased by the high aluminium treatment.

Phosphorus (Table V). Leaf phosphorus content was increased by both high nutrition and high manganese treatments at all calcium levels. The increase caused by high manganese was particularly marked with the plants receiving low aluminium. High aluminium significantly depressed leaf phosphorus content, at both nutritional levels, and also suppressed to some extent the effect of high manganese in increasing leaf phosphorus content, particularly under conditions of low nutrition.

Potassium (Table IV). Leaf potassium content was decreased by high calcium treatment and increased by high nutrition treatment, irrespective of the level of

TABLE IV.

Sand-culture experiment. Leaf contents of Ca, Mg and K as % of oven-dry weight.

Levels of applied Al and Mn	Levels of applied Ca	Low nutrition			High nutrition		
		Ca	Mg	K	Ca	Mg	K
Low Al Low Mn	Low	1·38	0·38	3·74	0·69	0·49	4·94
	Medium	2·52	0·34	2·83	1·07	0·51	4·04
	High	3·16	0·26	2·57	2·06	0·43	3·78
Low Al High Mn	Low	1·00	0·25	3·65	0·79	0·51	5·43
	Medium	2·83	0·49	3·64	2·45	0·62	4·20
	High	2·19	0·31	3·67	2·31	0·47	4·64
High Al Low Mn	Low	0·84	0·29	4·06	0·73	0·40	4·88
	Medium	1·45	0·29	4·31	1·44	0·44	4·56
	High	1·80	0·27	3·61	1·99	0·41	4·15
High Al High Mn	Low	0·94	0·24	4·88	1·09	0·50	5·55
	Medium	1·49	0·30	4·30	2·07	0·45	5·53
	High	1·56	0·23	3·41	1·61	0·43	4·54

applied aluminium or manganese. High manganese increased leaf potassium content at all levels of applied calcium while high aluminium increased it only at the low and medium levels.

Manganese (Table V). High manganese treatment greatly increased leaf manganese content. No consistent differences in manganese contents were at first observed between plants receiving low and medium calcium levels, but both had higher contents than had plants receiving high calcium treatment. The results of further investigation (not quoted in this paper) suggest that leaf manganese content increased consistently with decrease in the level of applied calcium. High aluminium decreased the leaf manganese content, this effect being most pronounced in the low nutrition group of plants. High nutrition treatment significantly decreased the manganese content of plants receiving high levels of manganese and low levels of aluminium, but it increased the manganese content of plants receiving high levels of both manganese and aluminium. The net effect of this was that no significant difference existed between the manganese contents of plants receiving high manganese together with either low or high aluminium level, a point of some importance when considering the diminished expression of toxicity shown by the latter.

TABLE V.

Sand-culture experiment. Leaf contents of N, P, Mn, Fe and Al; N and P as %, Mn, Fe and Al as p.p.m., of oven-dry weight.

Levels of applied Al and Mn	Levels of applied Ca	Low nutrition					High nutrition				
		N	P	Mn	Fe	Al	N	P	Mn	Fe	Al
Low Al Low Mn	Low	3·60	0·48	81	115	179	4·25	0·69	73	129	298
	Medium	3·73	0·46	114	115	157	4·30	0·68	62	94	138
	High	3·52	0·43	61	127	173	4·34	0·61	84	77	236
Low Al High Mn	Low	3·64	0·74	4,758	257	290	4·33	0·91	3,180	160	280
	Medium	—	0·93	6,000	201	156	—	1·21	4,415	196	107
	High	4·31	0·72	2,321	217	297	4·69	1·05	1,931	172	264
High Al Low Mn	Low	3·40	0·31	59	160	334	4·27	0·44	54	156	229
	Medium	3·33	0·34	77	249	251	4·05	0·44	136	120	189
	High	2·98	0·31	87	191	327	4·01	0·48	61	163	241
High Al High Mn	Low	3·16	0·30	1,816	171	312	4·02	0·55	4,440	175	212
	Medium	—	0·37	1,592	186	271	—	0·73	2,177	220	90
	High	2·98	0·37	1,453	196	272	3·98	0·56	1,736	165	319

Aluminium (Table V). High aluminium treatment slightly increased the leaf aluminium content of all plants receiving low nutrition treatment, but had no consistent effect under high nutrition conditions.

Iron (Table V). Leaf iron content was increased by both high nutrition and high manganese treatments, the effect of the latter being particularly well marked with plants receiving low aluminium.

Calcium and magnesium (Table IV). Calcium, magnesium and potassium contents in the leaf interacted in a similar way to that found in the soil-culture experiment. Calcium and potassium, under the influence of the applied calcium level and

in the absence of manganese toxicity, varied inversely, the proportion of magnesium in the total base content remaining constant.

DISCUSSION.

The main effect shown in the soil-culture experiment was a reduction in plant vigour at soil pH values of the order of 4·5 under conditions of low nutrition. The low soil pH itself is not likely to have directly caused this depression of growth, for plants growing at the same pH, but under normal nutrition conditions, grew almost as well as those growing at higher pH values, and in one or two cases even better. Nor is it likely that aluminium toxicity played any large part, for the affected plants in the soil-culture experiment did not show the type of stunting developed in the sand-culture experiment, and showed no depression in leaf phosphorus content such as that caused by the application of high aluminium treatments in the latter experiment. The depression in vigour is more certainly linked with the high manganese levels found in the plants when growing at the lowest pH level.

The variation in the magnitude of the manganese toxicity effects shown by plants growing in the three soils used in the soil-culture experiment seems to be related to the exchangeable calcium/exchangeable manganese ratios of the soils. The clay soil (S_1) had by far the highest ratio (Table VI) and so plants grown in it might be expected to

TABLE VI.

Exchangeable cation status of experimental soils as received from the field.

Soil	pH	m.e./100 gm.						Exchangeable Ca / exchangeable Mn
		Exchange capacity	Ca	Mg	K	Na	Mn	
S_1	4·8	32·00	11·40	1·75	0·53	0·31	0·72	15·83
S_2	5·1	10·00	1·85	0·41	0·08	0·14	0·40	4·63
S_3	4·4	7·40	0·37	0·28	0·03	0·15	0·18	2·06

have lower manganese contents than plants of the other two soils (Kipps, 1947 ; Hewitt, 1948). The very fine sandy loam had a lower exchangeable calcium/exchangeable manganese ratio than had the loam, however, and yet produced less marked toxicity effects than did the latter. It must be concluded that the loam possessed a higher content of readily available manganese than did the sandy loam. This seems probable for it contained more than twice as much exchangeable manganese and also had a much lower exchangeable hydrogen/exchangeable manganese ratio.

The high levels of manganese used in the sand-culture experiment caused severe manganese toxicity and resulted in the associated nutritional disturbances being much more marked than in the soil-culture experiment. From both experiments it would appear that manganese toxicity can result in necrotic spotting of the leaf, bine and petiole, together with distortion of the leaf lamina and a general stunting of the plant. The soil-culture experiment suggests that these symptoms can be largely eliminated, and plant vigour can be maintained, by the application of lime and/or

liberal fertilizer dosage to the soil. The general symptoms of manganese toxicity are associated with the development of abnormally high levels of nitrogen, phosphorus, potassium and manganese in the plant. Under conditions of extreme toxicity an additional effect is introduced, viz. a disturbance of iron metabolism with the appearance of leaf chlorosis and of increased amounts of iron within the leaves. Aluminium toxicity is mainly expressed by a general stunting of the plant and by a depression of leaf phosphorus content. These effects of aluminium toxicity can considerably modify the typical symptoms of manganese toxicity when the two treatments are applied together.

These last two points suggest the presence of at least two separate effects in manganese toxicity. The depression of manganese toxicity symptoms, consequent on a decrease in leaf phosphorus content caused by aluminium toxicity, suggests that some particular effect on phosphorus metabolism is involved. In addition the appearance of leaf chlorosis, together with high leaf iron contents in affected plants, suggests an " inactivation " of iron within the leaf, supporting the theory of Somers and Shive (1942) that a reciprocal relationship exists between iron and manganese in the plant. This sub-division of manganese toxicity effects into several separate reactions confirms some of Millikan's findings with flax (1949), in which he reported spot necrosis and iron chlorosis as being separate responses to manganese toxicity.

The interaction between calcium, magnesium and potassium contents of the leaf, observed to occur in similar fashion in both experiments, has not been commented on in detail. This interaction consisted of mutual replacement of calcium and potassium, with little change in the proportion of magnesium in the total base content ; it confirms findings by Van Itallie (1938), Bear and Prince (1945), Lucas and Scarseth (1949) and others, and demonstrates that a given amount of available potassium in the soil will be more efficiently utilized at lower levels of soil pH or calcium.

SUMMARY.

1. The effect of soil pH on hop growth was investigated at Wye College in a soil-culture experiment under conditions of low and normal NPK nutrition, and with three types of soil at four levels of pH ranging from 4·5 to 7·5. With normal nutrition, growth and vigour appeared to be little affected by soil type or pH within the range covered by the trial. With low nutrition, growth and vigour were reduced by manganese toxicity at pH 4·5, but were more satisfactory at higher levels of pH.

2. The effects of high levels of applied manganese and aluminium were investigated at low and high levels of NPKMg nutrition in a sand-culture experiment with three levels of applied calcium. Symptoms of manganese and aluminium toxicity were produced and are described. Manganese toxicity was reduced at high levels of nutrition and of applied aluminium. The latter appeared to modify the manganese toxicity symptoms by inducing phosphorus deficiency.

3. Visual symptoms of manganese toxicity were accompanied by the development of high contents of nitrogen, phosphorus and potassium in the leaf. In cases of severe toxicity, a leaf chlorosis suggestive of iron deficiency was observed ; this chlorosis was, however, associated with an increase in the total iron content of the leaf.

4. In both soil- and sand-culture experiments, leaf contents of calcium and potassium showed mutual replacement, the proportion of magnesium being little affected.

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PRUNING TRIALS WITH COX'S ORANGE PIPPIN APPLE

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This paper records the growth and cropping, up to the 14th year, of Cox's Orange Pippin trees on the vigorous M.II rootstock pruned to two different shapes, open-centre and delayed open-centre, and by three pruning methods, renewal (Thompson, 1949), established-spur (Grubb, 1932), and regulated (Preston, 1954a). Few experimental comparisons of these tree shapes and pruning methods have hitherto been made and, in many earlier pruning trials in England, differential treatments were deferred until three or four years after planting ; the treatments in this trial, however, began with the heading back of the newly planted trees. Papers dealing with the technique of tree forming and with the early-bearing phase of this trial have already been published (Preston, 1949 ; 1952 ; 1954b). The pruning terms used in this paper are those defined and recommended by the Horticultural Education Association (1955).

Materials and treatments.

Maiden trees were planted during the winter of 1945–46 on soil of the Malling Series of sandy-loam texture at 18 × 20 feet. Single trees receiving each of the following treatments were distributed within twelve randomized blocks : open-centre, established-spur pruning ; open-centre, renewal pruning ; delayed open-centre, established-spur pruning ; delayed open-centre, renewal pruning ; regulated pruning. The Cox rows alternated with those of Laxton's Superb on the same rootstock. The plot was clean cultivated, with autumn weeds allowed to grow each year until April 1956 when it was grassed.

Tree shaping.

Open-centre. The trees were headed back to 30 in. at planting and any feathers were removed. Primary branches were limited to three ; these had their leaders tipped to obtain a secondary branch framework. Leader tipping continued each year and suitably placed laterals were tipped to form branches to fill in the tree's framework ; inward growing shoots were removed, so as to build an open-centre shape.

Delayed open-centre. The trees were headed back to 33 in. at planting and any feathers were removed. Successive tiers of framework branches were secured around a central leader over a period of years. Each branch was treated as a single unit and was not allowed to fork. At seven years old, when the trees were eight to nine feet high, the central leader was cut back into three-year-old wood to a framework branch.

Pruning methods.

Established-spur pruning. Leader tipping became lighter as the tree framework developed and ceased at the twelfth year except on laterals required as replacement

leaders. Strong laterals not required for new branches were cut out ; very weak ones were shortened to 3 in. to form induced spurs. Laterals of medium vigour, mainly on the outside of the tree, were left uncut to fruit ; these were shortened back later to a spur or, if they were becoming crowded or too large, removed altogether. Laterals from spur systems and induced spurs were shortened to 1 in. The thinning and shortening of spur systems was done systematically each year, thus avoiding a major operation in any one year that might affect cropping.

Renewal Pruning. Leader tipping was light and was discontinued after the ninth year except on replacement leaders. About one-third of the one-year laterals were cut back each year to two or three inches to provide more the following year, the remainder being left uncut. Some two-year laterals were shortened to six or seven fruit buds each year, the remainder being left uncut to become three-year laterals. Owing to vigorous growth during the early years, many three-year laterals were left in for a further year before they were stubbed to produce more one-year laterals.

Regulated pruning. The trees were headed back to 30 in. at planting and feathers were removed. The number of primary branches was not restricted and during the next two years no more than three leaders were tipped each year ; leader tipping then ceased. Laterals were neither spur-pruned nor shortened. Crowded, thin or weak laterals were removed, irrespective of age, and also those that competed with the unpruned leaders.

During the first seven years when the trees' frameworks were being formed, all three pruning treatments were carried out by one man. Thereafter the trees were pruned, under supervision, by four workers each year. Each pruning treatment was completed before proceeding to another, to ensure that any personal bias on the part of the workers was distributed within a treatment.

RESULTS.

Tree size.

Trunk girth measurements at thirteen years of age showed that there was significant interaction between tree shape and pruning method, open-centre trees being larger than delayed open-centre trees when renewal-pruned. No significant effect occurred with established-spur-pruned trees (Table I).

TABLE I.

Mean trunk girth (cm.) at 13 years.

Open-centre		Delayed open-centre		Regulated	Sig. ratio (P=0·05)
Established-spur	Renewal	Established-spur	Renewal		
43·5	44·8	44·4	42·4	44·2	1·05

Data for tree height and area of branch spread (mean diameter squared) showed that regulated trees were slightly shorter and more spreading than either renewal or established-spur-pruned trees. Comparing the two tree shapes under different

methods of pruning the results are similar to those for trunk girth, open-centre trees being larger than delayed open-centre ones when renewal-pruned but the reverse when they were established-spur-pruned (Table II).

TABLE II.

Tree height (m.) and area of branch spread (sq. m.) at 13 years.

	Open-centre		Delayed open-centre		Regulated
	Established-spur	Renewal	Established-spur	Renewal	
Height	4·0	4·2	4·4	3·9	3·9
Area	32·8	34·9	34·5	33·2	35·4

Weight of prunings.

During a ten-year period the total weights of prunings removed from trees under the three pruning methods were very similar. The ratio of new to old wood removed, however, differed considerably not only between treatments but also between two consecutive five-year periods of the trial (Table III). These ratios show that, once trees have come into bearing, considerably more old wood is removed from trees under a " light " method of pruning (regulated) than from relatively " hard " pruned trees (established-spur).

TABLE III.

Total weight of prunings, 1949–58 ; ratio of new to old wood.

	Regulated	Established-spur	Renewal
Weight (lb.)	106·2	110·8	115·8
Ratio $\frac{\text{new wood}}{\text{old wood}}$			
4-8 years	1 : 2	3 : 1	1 : 1
9-13 years	1 : 5	1 : 1	1 : 4

Time taken to prune.

When the trees were twelve and thirteen years of age, and considered mature, records were made of the pruning times for trees under the three pruning methods. In the first year the amount of pruning was less than that required in the second, which followed a wet summer ; the means for the two years are shown in Table IV. The relative times are the important ones since in this trial, with randomized treatments, the actual pruning times include the moving of pruning stools from one tree to the next, which was often several trees farther down the row, and placing the prunings under each tree for weighing. Renewal pruning enabled eight minutes per tree to be saved

compared with established-spur pruning. The regulated method afforded a further reduction in time, saving ten minutes per tree compared with renewal pruning. This saving of ten minutes per tree could be of considerable importance under commercial orchard conditions. Assuming that the density of an orchard was 150 trees to the acre, each of similar age and size, a saving of three working days per acre might result.

TABLE IV.

Time taken to prune a tree ; mean time at 12 and 13 years.

	Regulated	Renewal	Established-spur
Minutes per tree	26	36	44
Percentage reduction in time	Regulated < renewal		Renewal < established-spur
	28		18

Incidence of mildew.

A succession of dry springs, the use of captan instead of lime-sulphur, and the cessation of spraying with D.N.C./petroleum were probably contributing factors in building up a severe outbreak of apple mildew (*Podosphaera leucotricha*) in 1956. Infected spurs and shoot tips were cut out in May 1957 and 1958, and their volume recorded. Analysis of variance on these measurements showed that the amount of infection was not significantly affected by either shape of tree or method of pruning. The volume of material removed in 1958, however, was 62% less than that in 1957. Rigorous cutting out of visible infection, together with a protective spray programme, enabled this disease to be brought under control by 1959.

Cropping.

At seven years of age the renewal-pruned trees had borne more than twice as heavily, and regulated trees four times as heavily, as established-spur-pruned trees. At thirteen years of age the regulated trees had still borne the heaviest total crop though this did not differ significantly from that for renewal-pruned trees (Table V) ; both regulated and renewal-pruned trees bore more heavily than did established-spur-pruned trees ($P=0{\cdot}001$). The percentage increase in accumulated crop from regulated trees over renewal-pruned has been falling since the spectacular rise in the

TABLE V.

Total crop in lb. per tree (1949–58) at 13 years of age.

Established-spur	Renewal	Regulated	Sig. diff. ($P=0{\cdot}05$)
569·4	754·3	828·2	87·4

sixth year. Nevertheless, it took eleven years for the crops from trees under these two treatments to come within 20% of one another (Fig. 1). Shape of tree had no significant effect upon cropping at any period during the trial.

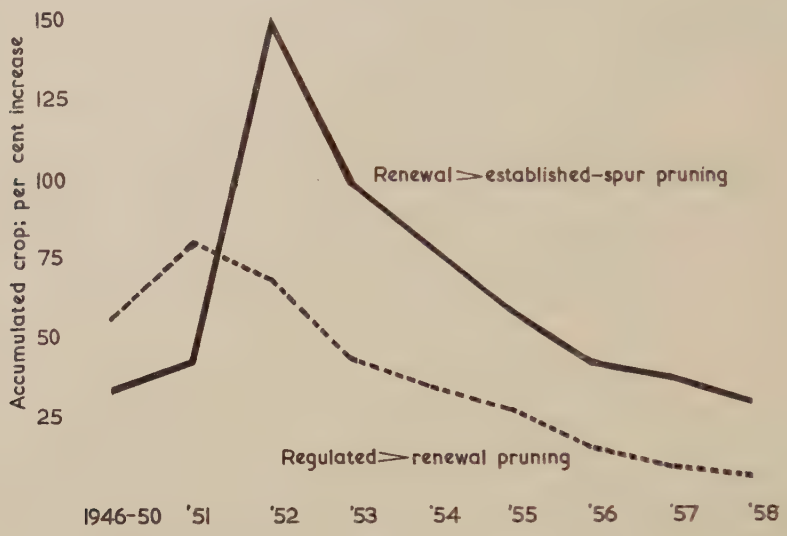

FIG. 1.

Per cent. increase in accumulated crop for established-spur, regulated and renewal methods of pruning.

Fruit size and quality.

The fruits were left unthinned each year and, on the whole, good quality fruit was produced from the trial.

In each of the years 1955–58 the Plot was divided into two and the fruit in each half was bulked from all trees under each pruning treatment separately. The fruit was then graded into the two commercial colour grades, "Fancy" (most red-coloured) and "Choice" (less red), and five size grades, from 2 in. in quarter-inch steps to 3 in. and over. Analyses of variance on the percentages of waste fruit, and of fruit in the colour and size grades, failed to show any significant effect of pruning treatment.

Analyses of variance were also carried out on the mean weight of 100 fruits for the years 1956–58. The only difference which was significant was in 1957 when established-spur-pruned trees carried larger fruits than renewal-pruned trees. The mean figures were :

	Renewal-pruned	*Established-spur-pruned*	
Mean weight (lb.)	23·8	25·3	(P=0·01)

The crop from renewal-pruned trees in 1957 was, however, 20% greater than that from established-spur-pruned trees and this probably accounts for the difference in mean fruit size. The fruit from regulated trees was intermediate in size between that from the other two pruning treatments in that year.

Hail damage.

A severe hailstorm on 6th August 1956 damaged a heavy crop of fruit. When the fruit had been picked and graded, one tray from each size grade was selected at random from each colour grade from each pruning treatment. To record hail damage twelve apples from one corner of each tray were selected. The assessment was made in two categories for damage : a rating of 1 for a single small spot or dent and of 2 where the fruit was severely marked. Thus the maximum figure for damage was 24 for any one sample. The mean category figures for damage for the different pruning methods and size and colour grades are shown in Table VI.

TABLE VI.

Hail damage, 1956 ; mean category for fruit damage (maximum 24).

Regulated	Open-centre		Delayed open-centre		Sig. diff. (P=0·05)
	Renewal	Established-spur	Renewal	Established-spur	
10·4	13·2	15·1	13·1	15·1	
Size grades (in.)	2-2¼	2¼-2½	2½-2¾	2¾-3	
	10·45	13·30	14·25	15·55	0·9
Colour grades	Choice		Fancy		
	12·5		14·3		

Analysis of variance on the data showed that the regulated trees were least damaged. Renewal-pruned trees were less damaged than established-spur-pruned ones but the difference was not significant. The proportion of damaged fruit in the different size grades differed significantly (P=0·001) but the amount of damage was not proportional to the surface area of the apple. Fruits therefore which ultimately became the largest may have been predominantly on the outside of the tree and thus more exposed. Apples in the Fancy (most red-coloured) grade were damaged more than those in the Choice grade (P=0·01), the best coloured fruits being generally those which are most exposed.

Deblossomed trees.

A few regulated and open-centre renewal and established-spur-pruned trees of Cox on M.II, adjoining those in the main trial, were deblossomed by hand for the first six years ; from the seventh year they were allowed to crop. The first crop almost equalled the accumulated crop, at seven years, from the normally treated regulated and renewal-pruned trees ; that from the formerly deblossomed established-spur-pruned trees was affected by a severe "June" drop. These relatively heavy first crops

did not induce irregular bearing and the subsequent crops from regulated and renewal-pruned trees have been heavier than those from the normally treated trees (Table VII).

TABLE VII.

Crop increase from formerly deblossomed trees over normally treated trees at 13 years.

	Established-spur	Regulated	Renewal
Percentage increase	3	30	40

Fruit set, calculated per 100 blossoms, was higher with the formerly deblossomed trees in their first year of cropping than with the normally treated trees ; so also was the percentage " June " drop (Table VIII). With both groups of trees, setting and

TABLE VIII.

Per cent. fruit set and " June " drop for normally treated trees, and formerly deblossomed trees carrying their first crop, at seven years.

	Number of fruit buds	Per 100 blossoms		Harvested fruits ; % of fruit buds
		Fruit set	" June " drop	
Normally treated trees				
Established-spur ..	170	23	20	16
Renewal	526	13	6	41
Regulated	908	11	4	42
Formerly deblossomed trees				
Established-spur ..	102	31	29	12
Renewal	573	23	12	62
Regulated	1,343	17	5	72

" June " drop became progressively higher as the degree of pruning increased from regulated (very light) to renewal (light) to established-spur (medium). Thus the better setting on the established-spur-pruned trees was nullified by severe " June " drop.

Before cropping, the deblossomed trees demonstrated a progressive increase in tree size with the lighter methods of pruning, regulated trees being the largest and established-spur-pruned the smallest with renewal-pruned intermediate. Compared with the normally treated trees at this stage, deblossomed regulated and renewal-pruned trees were 13 and 19% larger respectively in area of trunk cross-section ; deblossomed established-spur-pruned trees were 4% smaller than comparable normally treated ones.

Heavy successive crops altered the relative sizes of the formerly deblossomed trees. Open-centre established-spur-pruned trees were the tallest at thirteen years though they were still the least spreading ; regulated trees, and to a lesser extent renewal-pruned trees, had to be set-up and have their more spreading branches cut-up to keep them at their original spacing.

DISCUSSION.

This trial has shown that there is no special advantage in growing trees of Cox's Orange Pippin to the delayed open-centre shape rather than to the open-centre. This confirms experience with other scions in recent trials at East Malling, for example Laxton's Superb (Preston, 1957) and Worcester Pearmain. Indeed the satisfactory growth and cropping of the regulated trees, in which shaping received no special attention, suggests that tree shape may in the past have received too much attention by the pruner, with consequent loss of time and crop. In training the branches of a delayed open-centre tree, care was taken not to allow the main branches to fork but to extend in one direction only. Had forking been allowed, as is common with open-centre trees, serious congestion of branches might have arisen and caused difficulty in fruit picking. Delayed open-centre trees that were renewal-pruned needed more drastic branch spacing than did open-centre trees to allow the full development of fruiting laterals of different ages.

Established-spur pruning (Anon., 1959), although lighter than the older spur pruning method (Grubb, 1932), has proved a wasteful method of producing fruit under the good soil and growing conditions of this trial. By allowing some laterals to crop before working them back to spurs, it was possible to get the trees into bearing as early as renewal-pruned or regulated trees, but the crops were not as heavy. Much new wood from spur systems and induced spurs was removed and burnt each year. Under less favourable growing conditions, however, established-spur-pruned trees are capable of bearing as heavily as renewal-pruned (Preston, 1954b). In years of severe " June " drop, established-spur-pruned trees had a higher percentage drop than did either regulated or renewal-pruned ; this supports earlier work by Grubb (1924) who reported heavier fruit drop from leader-tipped trees than from untipped.

Renewal pruning is a lighter and more fruitful method than established-spur, and it is well suited to the growth habit of Cox. It is a more exacting method than either established-spur or regulated pruning and considerable care and skill is needed in the timely selection of replacement leaders. Three-year laterals, or in some cases four-year laterals, must be stubbed regularly to ensure a supply of maiden laterals along the branches. If insufficient stubbing is done there is little or no growth response.

Regulated pruning is a simple and quick method and unskilled workers soon acquire a degree of judgment in removing wood once the basic principles are explained. It has proved a highly efficient method for inducing Cox to bear early and heavily. The total weight of wood removed in pruning trees by this method was less than, though similar to, that from the other two methods (Table III) ; nevertheless fewer cuts were necessary since most of the prunings consisted of branch thinnings rather than shoots and leader tips. This method is well suited not only to filler trees, where early bearing is essential, but also to trees on vigorous and very vigorous rootstocks and, as this trial has shown, to permanent orchard trees where growth and soil conditions are suitable. Under less favourable conditions it might be wiser to use the renewal method or, under extreme conditions of poor growth, established-spur pruning. Experience with Worcester Pearmain, however, indicates that this popular pollinator variety for Cox responds well to regulated pruning under a wide range of soil conditions.

The trees in this trial were planted at a uniform experimental distance of 18 × 20

feet. Under commercial conditions the more upright and less spreading established-spur-pruned trees might be planted as permanent trees at 20 feet apart, giving 109 trees to the acre. The more spreading regulated and renewal-pruned trees would probably need 24 feet, giving 75 trees to the acre. At these tree densities and with the cropping figures obtained in this experiment, the established-spur-pruned trees would have been outyielded, on an acreage basis, by regulated and renewal-pruned trees during the first ten years. As regards total crop at thirteen years (Table V), however, there would have been very little difference between treatments at these theoretical distances of planting. The grower who proposes using one of the lighter methods of pruning, renewal or regulated, on Cox trees on a vigorous rootstock such as M.II or MM.104, is faced with two alternatives : firstly, that of planting permanent trees only, at a distance of perhaps 24 feet square, so as to allow ample room for soil and grass management ; secondly, that of planting more closely at 17 feet square, then cutting back, and later grubbing out, one-half of the number of trees per acre when overcrowding makes management difficult. The lessening of wind damage to blossoms, fruit and leaves, and the increased cropping resulting from a denser planting, especially in exposed situations (Preston, 1960), seem to favour the second alternative.

Regulated and renewal-pruned trees that were deblossomed for the first six years formed large frameworks before they were allowed to crop. This unconventional method of tree-building did not result in any appreciable loss of crop when the trees were allowed to fruit in the seventh year, compared with the accumulated crop of normally treated trees. Subsequently, the former cropped more heavily than did the latter. A similar result was reported for trees of Laxton's Superb (Preston, 1957). Such a treatment might be of considerable use to an established grower who may be less concerned than a new grower in securing early crops, provided he can get increased crops later. The trees were deblossomed by hand but the development of a reliable deblossoming spray would be necessary for use on a large area of trees.

Important effects of light pruning methods, such as regulated and renewal, on the blossoming of Cox should not be overlooked. Rogers and Preston (1947) have shown that blossoms on one-, two-, and three-year laterals open later than do those on older spur systems. As these lightly pruned trees have more of this younger wood than do established-spur-pruned trees, the chances of their blossoms meeting good pollination conditions, and of possibly escaping frost damage in some years, are greater.

Apart from the early years when fruit from established-spur-pruned trees was rather large, and again in 1957 when they carried a relatively light crop, pruning method had little effect upon fruit size once the tree began to bear heavily. Methods of assessment for fruit size and quality in field trials of this nature need further study. Mean fruit size gives little or no indication of the proportion of fruit in the important market size grades. Commercial grading of the fruit, as practised in this trial, was possible by dividing the Plot into two and bulking the crop from half the number of trees in each treatment ; but twofold replication proved inadequate in the analysis of variance. Increased replication, within the limits of this trial, could only have been secured by reducing the quantity of bulked fruit in each replicate, with the consequent risk of there being very small quantities of fruit in some size grades The proportion of fruit in the different size and quality grades is of fundamental importance where results are to be interpreted for the grower.

Pruning costs with mature bush trees of Cox with Worcester pollinators can

account for 10–14% of the total cultural costs.* The wider use of light and quick pruning methods, such as regulated pruning, could under suitable conditions reduce this percentage, especially in young orchards. Two further methods of reducing the time and labour of pruning are under trial at East Malling with dessert apples : firstly, by using pneumatic pruning tools, for which the regulated method is particularly suitable once the trees are about eight years old; secondly, by pruning trees in alternate years instead of annually. This latter method, if successful, might enable growers to reduce substantially their pruning costs.

SUMMARY.

Winter pruning trials with the apple Cox's Orange Pippin on M.II, planted in 1945 on a loam soil, included open-centre and delayed open-centre tree shapes, and established-spur, renewal and regulated methods of pruning.

Data are presented and discussed on tree size, weight of prunings, time taken to prune, incidence of mildew (*Podosphaera leucotricha*), total crop at different periods, fruit size and quality, hail damage, and the behaviour of trees that were deblossomed during the early years.

Shape of tree had no direct effect upon growth and cropping, fruit size or quality. Regulated trees took the shortest time to prune and bore the heaviest crops. Established-spur-pruned trees took the longest time to prune and yielded least fruit. It took eleven years before the crops from renewal-pruned trees came within 20% of those from regulated trees.

Trees that were deblossomed for the first six years were larger than normally treated trees. Their first crop almost equalled the accumulated crop from normally treated trees and they surpassed the latter in their later crops.

The practical aspects of the trial, and means of further reducing the time and labour in pruning, are discussed.

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BOOK REVIEWS

ASPARAGUS. By A. W. Kidner. 2nd Edition. (London : Faber & Faber. 1959. Pp. 184, illus. Price 25s.)

Knowledge acquired as a result of many years' experience cannot fail to be of value to anyone interested in the subject concerned. The revised edition of Mr. Kidner's book will undoubtedly interest all asparagus growers, amateur or professional. Mr. Kidner grows asparagus on a field scale but his book will appeal equally to the amateur whose chief concern may well be the production of first quality "buds" for his or her own table.

Asparagus is produced commercially under widely differing conditions, particularly of soil, ranging from the reclaimed sand dunes of the Lancashire coast to the heavy loams of parts of the Vale of Evesham. Opinions as to the best methods of cultivation to adopt will naturally differ also. But Mr. Kidner's most important contribution to our knowledge of the asparagus plant relates to the breeding and raising of plants. As a successful breeder of pedigree cattle he has for many years applied the principles of cattle breeding to asparagus breeding with considerable success. Whether the geneticists are prepared to support him in some of his theories is perhaps doubtful, but the "proof of the pudding is in the eating" and on this score Mr. Kidner's recipe would seem to be worth copying.

One wonders whether "Giant" asparagus of the type illustrated opposite page 20 in the book is really needed or desirable. To be confronted at table with such monstrosities might prove embarrassing and the photograph, excellent though it is of Mr. Kidner, is hardly likely to foster a new interest in asparagus.

The book is well presented, contains excellent photographs and diagrams and, if parts of the subject matter are somewhat controversial, it makes most interesting reading.

H.F.

MITES, OR THE ACARI. By T. E. Hughes. (University of London : The Athlone Press. 1959. Pp. 225, illus. Price 42s.)

Although the Acari have been the subject of many papers in English for several years past, they mainly relate to the taxonomic aspect, and a book devoted to these small animals has not been published in this country for many years.

Mr. Hughes's work is especially welcome since it presents a general survey of the group, both from a biological and from an anatomical point of view. The taxonomic aspect has not been covered, but the last chapter deals with modern trends of classification.

The author states that the book has been written to meet the needs of the general zoologists ; this claim is fully justified since it covers a very wide field, and also will prove invaluable to the acarologist and economic entomologist.

The chapter entitled "Mites as Plant Parasites" is rather too brief, but indicates the complexity of the problems associated with phytophagous mites and their hosts. The chapter on "Mites as Vectors" refers to many species of blood-sucking mites which

act as vectors of bacterial and virus diseases of their hosts, and many spread these infections to man and domestic animals. It is curious that the mites known to be carriers of plant virus diseases have not been mentioned in this chapter. The other chapters of the book discuss the cuticle, the exoskeleton and arrangement of body sclerites, the sensory organs and the central nervous system, the gnathosoma and the appendages, the alimentary canal, the reproductive system, and the respiratory system.

The bold, clear type makes the book easy to read, the references at the end of each chapter are adequate, and the exquisite line drawings, which are mainly the work of Mrs. T. E. Hughes, add much to the value of the work.

A.M.M.

PLANT GROWTH SUBSTANCES. By L. J. Audus. 2nd Edition. (London : Leonard Hill (Books) Ltd. 1959. Pp. 553, illus. Price 65s.)

The second edition of "Audus" (and what higher praise can be given than that this book is already alluded to thus?), as the start of a series of Plant Science Monographs from this publisher, sets a very high standard for subsequent authors.

The original lay-out has largely been retained, except that the chapter on abscission now has a more logical title and position, and a new chapter has boldly been added on surely the most controversial aspect of growth substances—the mechanism of action of the auxins. This fills a gap which was rather evident in the first edition, though it must be admitted that little positive information can be extracted from the formidable number of suggestions which have been made.

Quite apart, however, from this additional chapter, the text throughout has been painstakingly revised, sometimes extensively, as in the chapters on the chemistry of auxins, selective weed killers, and reproductive hormones. Even though the volume of published work since the first edition has been enormous, the author has at all times managed to retain a sense of proportion, and guides both the research worker and the "practical man" through the mazes of this difficult subject. The introduction of the gibberellins and kinins has been smoothly accomplished, and some excellent illustrations added of their effects on plants and tissues.

There is a glossary, and some valuable appendices which group together a very large number of results in the fields of rooting of cuttings, fruit-setting, herbicide response, and abscission effects. The subject index is extensive and the author index contains the page number of the reference in the bibliography as well as in the text (useful for " second authors "). The bibliography of more than 1,500 references is greatly improved in this edition, not only by doubling the number of citations, but by quoting the titles in full.

The format and printing are excellent ; one of the very few misprints (in an appendix, p. 427) even provided a refreshing concept to an E. Malling worker—"Non-rootstock" (for "Non-rooters").

No one but an enthusiast could undertake writing a large-scale book on this subject, and while the author's interest in the topics discussed has made the text eminently "readable", it has not produced that often-encountered attitude that growth substances are the alpha and omega of applied plant physiology.

H.W.B.B.

TRACE ELEMENT PROBLEMS IN NATURE. Edited by K. H. Schütte. (Botany Department, University of Cape Town. 1959. Pp. 55, illus. Price 5s.)

This booklet comprises four papers given in a Symposium held in the Botany Department of the University of Cape Town. The first, by Dr. Schütte, deals generally with the nature and causes of trace element deficiencies, and their role in plant growth. Dr. Amdurer then describes some geological aspects of soil formation and discusses the content, source and chemical nature of trace elements in the soil. His statement that the normal boron requirements of plants may be supplied from the air is open to criticism. Dr. Roach (formerly of East Malling Research Station) describes and discusses methods of diagnosis, including soil analysis, visual symptoms, indicator crops, plant injection and foliar sprays. There is one error in his list of essential elements—he does not include potassium, and furthermore he makes no reference to chlorine. Finally Professor Brock deals with trace elements in mammalian physiology and pathology.

This booklet is easy to read and should serve as a useful introduction for the person interested in trace element problems.

C.B.

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1. All **manuscripts** should be in double-spaced typewriting, with a good margin, and should be addressed to the Editor, East Malling Research Station, near Maidstone, Kent, England. Papers must be written concisely. Historical reviews should be as short as possible and only such references to literature as bear directly on the subject should be included. Tables and illustrations, if any, must be only such as are absolutely essential for clear presentation.

2. Authors of papers containing extensive **numerical observations** should consult the recommendations of the British Association Committee on Biological Measurements, 1927, obtainable from Burlington House, London, W.1, price 6d. Arrangements have been made whereby original data too extensive for complete publication may be deposited at the British Museum (Natural History), London, S.W.7, or with the Royal Society of Edinburgh, 22 George Street, and thus be available for consultation by other workers. Full bibliographical reference to the publication in which the results are summarized must be supplied with the data.

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